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BEHAVIOR OF FOUR SOUND RANGING TECHNIQUES IN AN IDEALIZED PHYSICAL ENVIRONMENT

SEPTEMBER 1978

By

W.B.MILLER

B.F. ENGEBOS

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U.S. ARMY
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US Army Electronics Research and Development Command
Atmospheric Sciences Laboratory
White Sands Missile Range, NM 88002

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Four contemporary sound ranging techniques are examined in an environment chosen to insure optimal performance characteristics for each. A data base is employed which is free of external contamination so that effects of truncation of arrival times and variations among algorithms are the sole contributors to observed differences in behavior. Noteworthy is the interplay which emerges between truncation effects and system response to meteorological errors. In addition, a direct comparison of techniques is given in context.

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INTRODUCTION

Within the artillery community, a renewed interest has been evidenced in the use of sound ranging as a passive mechanism for the location of hostile artillery and related functions [1,2]. Apparently, however, the subject is not without controversy, and no unified in depth treatment is evident. This lack of unity perhaps explains the existence of a considerable volume of literature containing a wide range of observation, interpretation, and opinion. Of special interest is a work of Hercz which has considerable scope and objectivity [3]; and historically, the works of Conant [4] make worthwhile reading.

To more effectively study the various problems peculiar to sound ranging, an effort was made in 1976 to construct a mathematical framework in which the sound ranging problem would be given a rigorous definition [5]. An offshoot of this study was a methodology whereby a hierarchy of sound ranging algorithms could be constructed based on physical assumptions concerning operating environment and on functional requirements of the algorithms themselves. Six such algorithms have been constructed and validated. Several properties of two members of this group are documented [6].

Of the above-mentioned six algorithms, one based on the simplest reasonable physical assumptions and with minimal functional requirements most nearly corresponded to a number of contemporary sound ranging techniques. This algorithm has been designated as Acoustic Location Program 1 (ALP-1).

In the study [6], certain behavior characteristics of ALP-1 were noted when the procedure was subjected to truncation of arrival times. Of interest also was the interplay exhibited between trucation levels and response to meteorological errors. It was natural then to ask whether the effects observed arose from peculiarities of ALP-1 or were traits held with other sound ranging schemes sharing common physical assumptions. To clarify this problem, three contemporary sound ranging techniques were examined on a side-by-side basis with ALP-1. It was recognized that perhaps straight analysis of the various techniques would yield the desired answers, but the course of action taken was considered more visible and expedient.

The first procedure chosen is derivable from information available in FM 6-122 [7] and utilizes a geometric approach in solving the sound ranging problem. This procedure corresponds to the standard field procedure which usually assumes the use of a six-microphone linear array. Use of the procedure produces a set of ten estimates of sound source location from which a single estimate is chosen. The ten points constitute a "polygon of errors," and when a median or mean technique is employed to derive the single source location estimate, the technique is called USRAN 1. For the controlled environment of this experiment, a median or mean technique may be employed without a significant difference in behavior. Under field conditions, departures from normal behavior in

estimates of arrival times give the median technique a distinct advantage in accurate target location.

USRAN 1 is a flexible program which will utilize up to six acoustic microphones with a minimum of three required. Inherent in the structure of this procedure is a graphical display availability which can prove useful for "on the spot" editing of arrival times. The error characteristics of ALP-1 and USRAN 1 are different, and the nature of the difference suggests that the two are mutually complementary.

Also, USRAN 1 and ALP-1 both allow for differing baseline geometries and may easily deal with loss or gain of function among the six acoustic microphones. USRAN 1 is a self-starting procedure, while ALP-1 requires an initial source estimate. ALP-1 appears to exhibit an accuracy potential which would suggest use of this algorithm as a "vernier" for a scheme such as USRAN 1.

In the same vein, a least squares refinement of estimates is possible, and a representative member of this class programmed by Lee [8] was readily available to the authors. In this presentation, that scheme will be called the Lee least squares algorithm. Like ALP-1, this computational process requires an initial estimate of source location. The results show that if initial source point estimates are sufficiently close to the true source point, the least squares algorithm and ALP-1 very nearly coincide. A little reflection will show that this must be the case. However, ALP-1 is considerably less sensitive to errors in source point location, while the least squares algorithm can at times tolerate larger errors in arrival times given good initial source point locations. This follows from the nature of the algorithms.

A final computational procedure was chosen reminiscent of that employed in USRAN 1, but with array flexibility sacrificed to obtain increased accuracy; i.e., this technique required a fixed and unalterable number of functional acoustic microphones. A technique of this nature designated as USRAN 3 utilizes six microphones [9]. A lesser number to the limit of three may be employed to construct an algorithm of this type, but as the number approaches three, the techniques merge into USRAN 1.

For the four sound ranging procedures mentioned previously, a physical environment exists in which all must exhibit optimal performance. In this environment, a meaningful side-by-side comparison of techniques is possible.

This environment may be characterized as follows: a flat featureless plane of uniform temperature and over which a wind of constant velocity is blowing. In such an environment, if spherical propagation of sound waves is assumed together with well-defined leading edges for all wave fronts, arrival times of such a front at any point on the plane may be calculated with great accuracy. It is then possible to examine effects of truncations in timing and system responses to meteorological errors individually, or in concert. Once the basic behavior traits of the

various systems are understood in this environment, effects of more complex environments may more readily be interpreted.

It is realized that a well-defined leading edge for wave fronts, and in fact the entire physical model, is an abstraction and that any real physical situation will be expected to depart from this simple model. However, presently, such considerations could obscure points fundamental to an understanding of system error behavior. It might be noted that any concept of "effective" meteorological results is the approximation of a real physical environment by one of exactly the simple form given above. In this light it would appear that there is justification for system comparison under the stated assumptions. For the purposes at hand, attention will be focused on truncation effects, system response to meteorological errors, and interaction of the two. Ranges are considered up to 30 kilometers, and flanking angles from 0 to 75 degrees. Flanking angle here is defined to be the angle measured clockwise from the perpendicular bisector of the array to the target.

As a mathematical convenience, the plane in the scenario previously mentioned will be made to coincide with the plane $Z = 0$ of a rectangular Cartesian system and maximum use will be made of symmetry to reduce data volume. Nonetheless, the amount of data necessary to complete this analysis is considerable. All data are available for interested readers, but only data selected on significant results will be included here. Results presented in most graphs or figures will be typical, or will be related to other results not presented by a predictable line of cause and effect. As will be seen, the behavior traits indicated and the comparison presented provide an understanding of the basic properties of the algorithms considered and will be used as a stepping stone to the study of more realistic physical models.

SCENARIO AND DATA BASE GENERATION

The physical environment to be described will be fundamental in the study to follow. It may be visualized as a flat featureless plane of uniform temperature continually swept by a wind of constant velocity. For mathematical convenience, a rectangular Cartesian coordinate system (X, Y, Z) will be assumed, with the above plane corresponding to the plane $Z = 0$.

Suppose that at time t_o, a blast occurs at the point (X_o, Y_o, Z_o). The assumption will be that a spherical wave front will propagate outward in such a fashion that if (X, Y, Z) obeys the relationship:

$$W(x, y, z, t) = [(x - x_o) - u(t - t_o)]^2 + [(y - y_o) - v(t - t_o)]^2$$

$$+ [(z - z_o) - q(t - t_o)]^2 - c^2k(t - t_o)^2 = 0, \qquad (1)$$

then (x, y, z) will lie on the wave front at time t. Here, the vector $(u, v, q) \equiv \vec{v}$ represents the wind and k the temperature in degrees Kelvin,

both from the original physical environment. The letter c is a constant whose value in this report will be taken as 20.06 consistent with the MKS system of units and the assumed physical modeling assumptions.

From the assumptions inherent in (1), the equation must satisfy the relationship

$$t = t_o + \frac{\sqrt{(\vec{v}\cdot\vec{x})^2 + [c^2k - (\vec{v}\cdot\vec{v})]\,(\vec{x}\cdot\vec{x})} - (\vec{v}\cdot\vec{x})}{[c^2k - (\vec{v}\cdot\vec{v})]} \qquad (2)$$

where $[(x - x_o), (y - y_o), (z - z_o)] \equiv \vec{x}$

Note that the mode of construction of each of the computational procedures to be examined assures that optimal performance may be expected when expression t is used in context to provide requisite arrival times for the estimation of (x_o, y_o, z_o).

It is intrinsic to (1) that in time an expanding wave front must possess a well-defined leading edge. This effectively bypasses one critical issue in the sound ranging problem, that of break point identification. This problem exists distinct from algorithm performance except as it affects the choice of a vector of arrival times. The reaction of a given algorithm to such errors is insensitive to the causes involved except when those causes possess a reasonable determinative structure. For such a case, advantage may be taken of such structure and a suitable algorithm fabricated. Among the procedures considered at this time, none possess this form of structure, but algorithms which may prove to be of merit exist on the horizon, and these algorithms utilize the idea of degradation of timing accuracy with range and other characteristics.

The problem of arrival time accuracy is complex and has points of ambiguity, at least at the current state of the art. Several factors influence the behavior of the problem, and a comprehensive random model is quite involved, although useful information may be gleaned from randomization of expression (2). For these reasons, at present, algorithm behavior is examined apart from considerations of the nature of arrival time errors. If such were included at this point, behavior traits might be introduced which would obscure points of interest which would otherwise be clear. The problem of arrival time accuracy and its error structure is currently being addressed.

For a preliminary examination of the chosen algorithms, a configuration of 66 systematically located sound sources was found to afford an adequate picture of behavior characteristics of interest. Source points were located at 5 to 30 kilometers at 5-kilometer intervals and along flanking angles of 0 through 75 degrees at 15-degree increments (figure 1).

Symmetry could be used in the placement of acoustic microphones to derive information equivalent to that supplied by the above configuration, but with only 36 source points. This method considerably

diminishes the volume of data to be treated and affords an adequate picture of the characteristics of interest in this study. A denser grid of source points could be used to spotlight frequency effects of truncation of arrival times but would not especially increase information in current context. In addition, all computational procedures exhibit continuity except for specified juxtapositions of source points and microphone locations; and after a point, behavior with respect to truncations, or general variation at a sufficiently small variance, must be smooth.

In the generation of timing data, a set of microphone positions (x_1, y_1), $\cdots, (x_6, y_6)$ was defined by

$$\left.\begin{aligned} x_j &= 7000 - 2000j \\ y_j &= -1000 \end{aligned}\right. \qquad j = 1, 2, \ldots, 6$$

where (x_j, y_j) is given in meters.

For a source point as described previously, definition of the wind vector (u, v, q) and the temperature k, will produce a vector of six arrival times. For present purposes, a wind vector of (0, 0, 0) and a temperature of 295°K were employed. Other values of wind and temperature were employed without altering basic results, and so were omitted.

Arrival times for all source points were calculated at the full accuracy of the HP 9830-A. Four increasingly degraded cases of timing accuracy were considered: full accuracy for initial verification which is not included, then 0.1-, 1-, and 10-millisecond truncation levels. The 100-millisecond truncation level was also examined but produced such erratic behavior in all algorithms that it was not included.

When the version of USRAN 1 is considered, the Lee least squares technique and the algorithm ALP-1 all may account for a loss of as many as three microphones without loss of function. Behavior of truncation effects together with microphone loss and errors in meteorological parameters is being addressed separately and introduces a number of interesting insights. This study should be available in the near future.

After figure 1, which indicates the relative positions of microphones and source points employed in this study, all figures will have a similar construction. Each will consist of four subfigures. The top two plots always indicate comparative miss-distances for the indicated versions of USRAN 1, USRAN 3, and the algorithm ALP-1, and for truncation levels of 0.1 and 1.0 milliseconds as specified. The bottom left plot always presents a similar format, but for a timing level of 10 milliseconds.

The bottom right plot is a special case, and presents maximum and minimum miss-distances at the 1.0-millisecond level for the Lee least

squares technique. The deviations were derived from the fact that four initial estimates for sound source location were routinely made. These estimates were at 12:00, 3:00, 6:00, and 9:00 o'clock and at a distance 20 percent of range of the midpoint of the microphone array to the target from actual target. In the Lee technique, an appreciable amount of variation was found among responses to these estimates. In ALP-1, almost no variation was observed; hence no special plot was required.

Note that the vertical scales used in a given figure change. This change is dictated by the behavior of the algorithms and is necessary if meaningful resolution is to be maintained.

EXACT METEOROLOGICAL INFORMATION

In this and the succeeding sections, the effects of timing information degraded by truncation are examined. In all situations presented, each algorithm is provided with the exact meteorological data as the data exist in the previously described physical environment.

In the examination of figures 2 through 7, which represent increasing flanking angles of 0 through 75 degrees, the most striking feature shared by all algorithms is the abrupt increase in erratic behavior when the 10-millisecond truncation level is reached. Also, observation shows that the degree of erratic behavior experienced by all procedures tends to increase with distance. Limited analysis in addition to that presented tends to indicate that truncation effects in this context would produce a stochastic process with an increasing trend as distance increases, and with a similarly increasing variance. One might also note that the Lee least squares algorithm presents considerable deviations between maximum and minimum values as source point estimates vary. Minimal miss-distances in this case lie near those of ALP-1, while maximum excursions appear quite large. This difference would indicate that the Lee least squares probably would have little "stand alone" capability and would require a good initial estimate to function.

Figures 2 and 3 show that at the 10-millisecond truncation level, USRAN 1, USRAN 3, and ALP-1 may exhibit quite different performance characteristics, but when figures 2 through 7 are examined together, algorithm behavior due to truncation effects shows a general behavior agreement.

Error increase with increasing flanking angle is evident through changes in scale; also lack of consistency in behavior at the various levels can be noted. All algorithms degrade in performance as flanking angle increases. It might be deduced that millisecond timing would be a worthwhile goal, with considerable returns in stability and accuracy over a wider area.

EFFECTS OF ARRIVAL TIME TRUNCATION IN THE PRESENCE OF UNIT ERRORS IN TEMPERATURE

This section concerns the effects on miss-distance of the earlier defined levels of truncation, but in the presence of unit variations (degrees Kelvin) in temperature. The plots show that effects of truncation at the 0.1-millisecond level indicate a definite and very nearly linear trend of increase of miss-distance with range. Though not included, ALP-1 has been shown to produce a more and more linear trace as timing accuracy increases.

Figures 8 through 19 are arranged in such a manner that side-by-side comparisons may be made between positive and negative unit effects in temperature at all flanking angles. In the case of 0.1-millisecond timing, no great difference is exhibited in unit effects between algorithms, but ALP-1 exhibits a reflexive mode when positive and negative errors are encountered. The figures show that as timing errors decrease, so does the amplitude of the variations in effect of ALP-1; and at sufficient timing errors, these effects disappear altogether. The miss-distance at maximum accuracy is almost exactly the average of miss-distances of ALP-1 for positive and negative temperature fluctuations.

A 0-degree flanking angle and a 1.0-millisecond truncation of arrival times still retain an indication of linearity of miss-distance with horizontal range, but this tendency is not so pronounced as that observed for more accurate arrival times. For a truncation at 10 milliseconds, all evidence of linearity is lost except by use of statistical methodology. At higher flanking angles, similar results are encountered, but with increases in magnitude of miss-distances. In all cases, the truncation at 10 milliseconds produces a sudden increase in erratic behavior and loss of linearity of unit effects. Notice that at the 10-millisecond truncation of arrival times, the algorithms other than ALP-1 show a tendency to be reflective.

The Lee least squares algorithm exhibits a distinct separate behavior for varying initial estimates, with the most favorable values being near those of ALP-1 (top right plot of figure 13), with a good agreement of values occurring at 30 degrees. An increasing value of scale on the plots shows that all procedures exhibited greater errors as flanking angle increased.

Considerably more interpretive analysis is possible, but consistent with the purposes of this investigation, these must remain for consideration at some future time. At present, an examination of errors introduced by a combination of truncation of arrival times and unit errors in wind will be considered.

WIND ERRORS PERPENDICULAR TO ARRAY BASELINE

For the wind conditions utilized, little effect occurred due to unit errors in wind blowing perpendicular to the array baseline. This may be

observed by comparing figures 2 through 7 with those of 20 through 25. This holds true at a truncation level of 0.1 millisecond for all algorithms to a greater or lesser extent, with ALP-1 yielding near zero miss-distances from flanking angles of 0 to 60 degrees. At 75 degrees, ALP-1 remains near zero, but both USRAN 1 and USRAN 3 exhibit a strong increasing trend with distance.

Increases in miss-distance with increasing flank angle and target distance are evident, as in previous sections, with sudden increases in erratic behavior at the 10-millisecond truncation level readily observed. The Lee least squares algorithm closely parallels ALP-1 in behavior of its minimum miss values.

The question arises as to whether the apparent independence of results to perpendicular winds is in fact true or reflects a second-order effect. Toward this end, data were generated including a perpendicular wind of 50 knots. The ALP-1 algorithm was then utilized to find a source point at 10 kilometers range and 0 degrees flanking angle. Millisecond truncation produced a miss-distance of 3 meters, well within system roundoff error.

Additional information may be derived from the more advanced algorithms, and strong evidence of independence exists in this area. It might be observed that if an array is not linear, the observed behavior of perpendicular wind ceases to hold. A more formal presentation on the problem of independence may be presented at a later date. Presently, the differences in algorithmic behavior seen here are believed to be due to the technique USRAN 1 and USRAN 3 use for wind correction.

WIND ERRORS PARALLEL TO ARRAY BASELINE

Observation of figures 26 through 37 indicates that unit wind errors parallel to the array baseline exhibit a near perfect linear dependence of miss-distance on range when subject to truncation levels at 1.0 milliseconds or better at flanking angles from 0 to 30 degrees. At higher flanking angles, slight deviations from linearity are experienced.

A reasonable consistency is evidenced between algorithms, with ALP-1 exhibiting a reflective behavior at smaller truncation levels. As flanking angles increase, accuracy deteriorates and this deterioration holds also for increasing distance but to a lesser extent. As usual, a considerable increase in erratic behavior of miss-distances occurs at a truncation level of 10 milliseconds, and consistency of algorithms lessens considerably. Again as usual, the minimum miss values of the Lee least squares lie close to those of ALP-1.

As a whole, the various algorithms behave a bit more stably with regard to winds parallel to array baseline than those experienced with temperature.

A 5-METER/SECOND ERROR IN SOUTH AND WEST WINDS, AND A 5-DEGREE KELVIN ERROR IN TEMPERATURE

In this section meteorological errors of 5°C and 5 meters/second in both wind components are considered. These errors are used to demonstrate the linearity of unit effects due to errors in met parameters. An additional reason for utilization of errors of this magnitude is a demonstration of the relative independence of errors in meteorological variables when arrival time accuracy is adequate for corrective modes. These errors are not to be construed as representative of field type meteorological errors which would hopefully be smaller in magnitude.

Figure 38 indicates a linearity which appears to be strongest at a range in excess of 10 kilometers. Truncations of arrival time at the 0.1- and 1-millisecond level produce similar results. On the whole, linearity is preserved quite well at a 10-millisecond truncation, considering previous results. In this case, one would suspect a cancelling effect to be in operation, that is, a favorable interaction of meteorological conditions.

Figure 39 describes the behavior of the various algorithms for a 15-degree flanking angle. All techniques preserve linearity through 1.0-millisecond truncation of arrival times but deteriorate seriously at a 10-millisecond truncation.

Figure 40 begins to exhibit a divergence of unit effects between ALP-1 and USRAN 1 and USRAN 3. Observe that linearity of unit effects persists for all the algorithms through millisecond truncation of arrival times, but degrades at the 10-millisecond truncation, the typical behavior pattern. The behavior continues in much the same fashion through figure 43. The differences in techniques are not startling. However, at the higher flanking angles, note that these differences tend to be obscured to the casual glance by increasing vertical scale.

Overwhelming the variations in miss-distance for the different algorithms are effects due to the variations in timing truncation. This, the authors feel, is a most important consideration.

Whatever the reasons, a logical first step in developing enhanced sound ranging capabilities appears to be through some means of enhancing arrival time accuracy toward the nearest millisecond and preserving linearity of unit effects with distance. Then more powerful algorithms now available can be utilized. Without such timing enhancement, one logical system for obtaining maximum accuracy over an extended area appears to be a composite algorithm encompassing the best features of several algorithms. A number of such configurations are currently being studied to determine stability and field worthiness, with at least one showing promise.

As a final point, it should be stressed that the interplay between timing and required accuracy of meteorological data in no way implies

that meteorological information is not essential to accurate sound ranging. In fact, field accuracies in the foreseeable future would tend to indicate that a high degree of importance must be placed on accurate meteorology.

The behavior of the advanced algorithms ALP-2 and ALP-2T as demonstrated in tables 1 through 3 shows striking reductions. For the larger flanking angles (greater than 45 degrees), ALP-2T gives good results for all timing accuracies. This feature may possibly be exploited into a composite type algorithm to effectively extend the zone of coverage by sound ranging. Note also that by putting bounds on the timing, of the blast, in algorithms ALP-2 and ALP-2T the instability as observed in tables 2 and 3 can be prevented. This analysis will be forthcoming.

CONCLUDING REMARKS

In the performance of this comparison, one fact seems to predominate. For all ranges and flanking angles considered, accuracy deteriorates drastically when arrival times are truncated at the nearest 10 milliseconds. This phenomenon occurs for all techniques considered to a greater or lesser extent. In addition, linearity in distance of unit effects for wind and temperature, which are evident at 0.1- and often at 1.0-millisecond truncations of arrival times, are, in the majority, totally lost when accuracy is reduced to a 10-millisecond truncation. Therefore, it may be concluded that timing accuracy approaching a millisecond is needed.

Due to the problem of extreme stratification of sampling, a direct statistical comparison is difficult and adds nothing to the results of this study. In all cases, one might consider that no statistics are involved, but rather a tabulation of results from numerical algorithms.

Note that when wind or temperature deviations are introduced for an individual case, smaller or larger values of miss-distances do not guarantee how a given technique performs in general. For example, if zero miss-distance is observed at 20 kilometers without adjustment for meteorological conditions, then certainly the technique could not be called good, but lucky.

A general statistically unsupported statement is that USRAN 3 appears to offer improvement over USRAN 1, and ALP-1 compares favorably with USRAN 3. Also, if initial guesses are of sufficient accuracy, the Lee algorithm and ALP-1 exhibited similar behavior characteristics.

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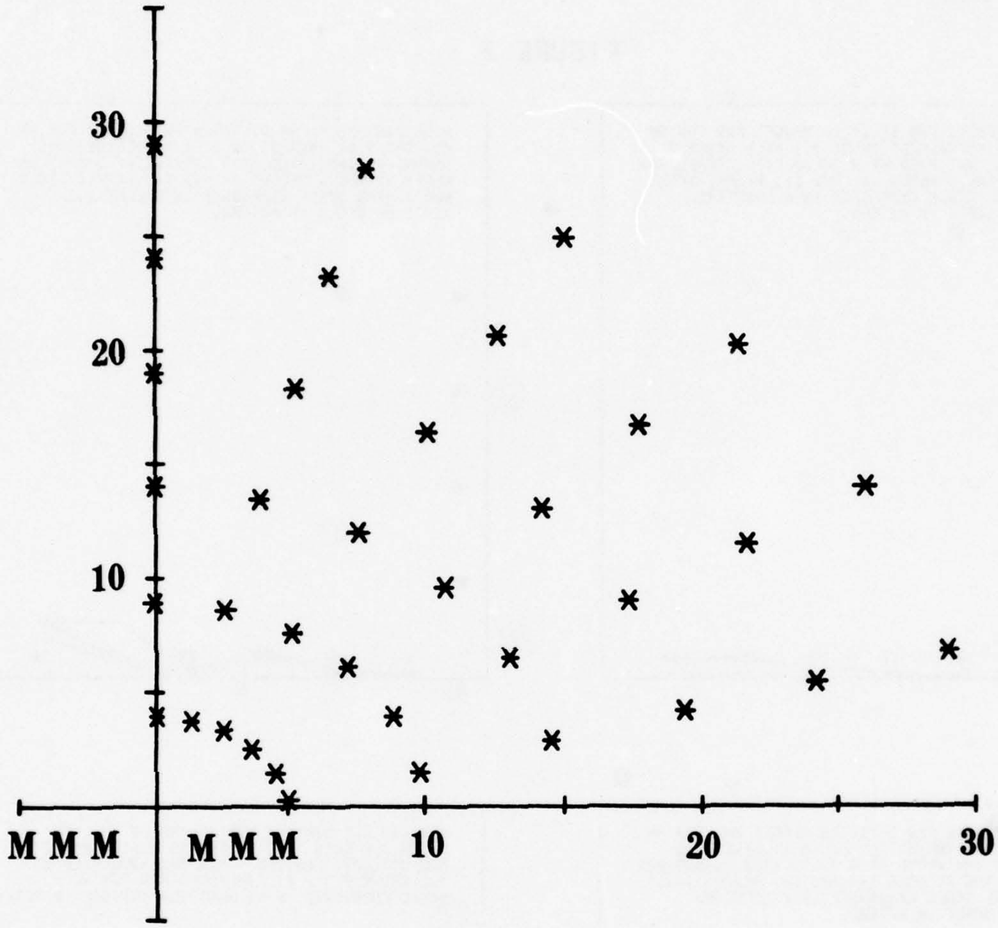
Source locations utilized in the evaluation of USRAN 1, USRAN 3, ALP-1, and the Lee least squares algorithm. Source positions are designated by asterisks, microphones by (M).

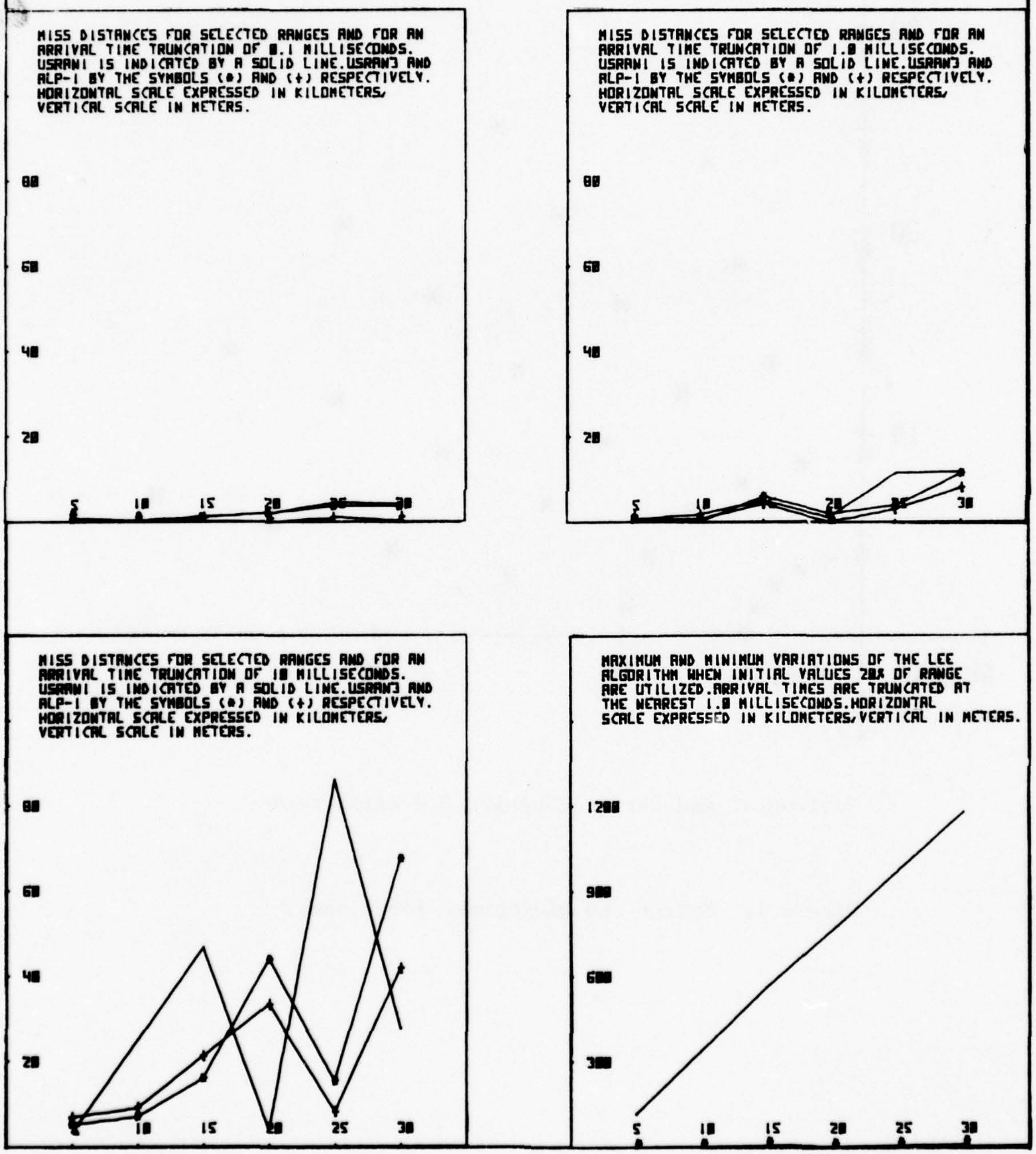


Horizontal and vertical scales 5.0 kilometers

Figure 1. Source and microphone locations.

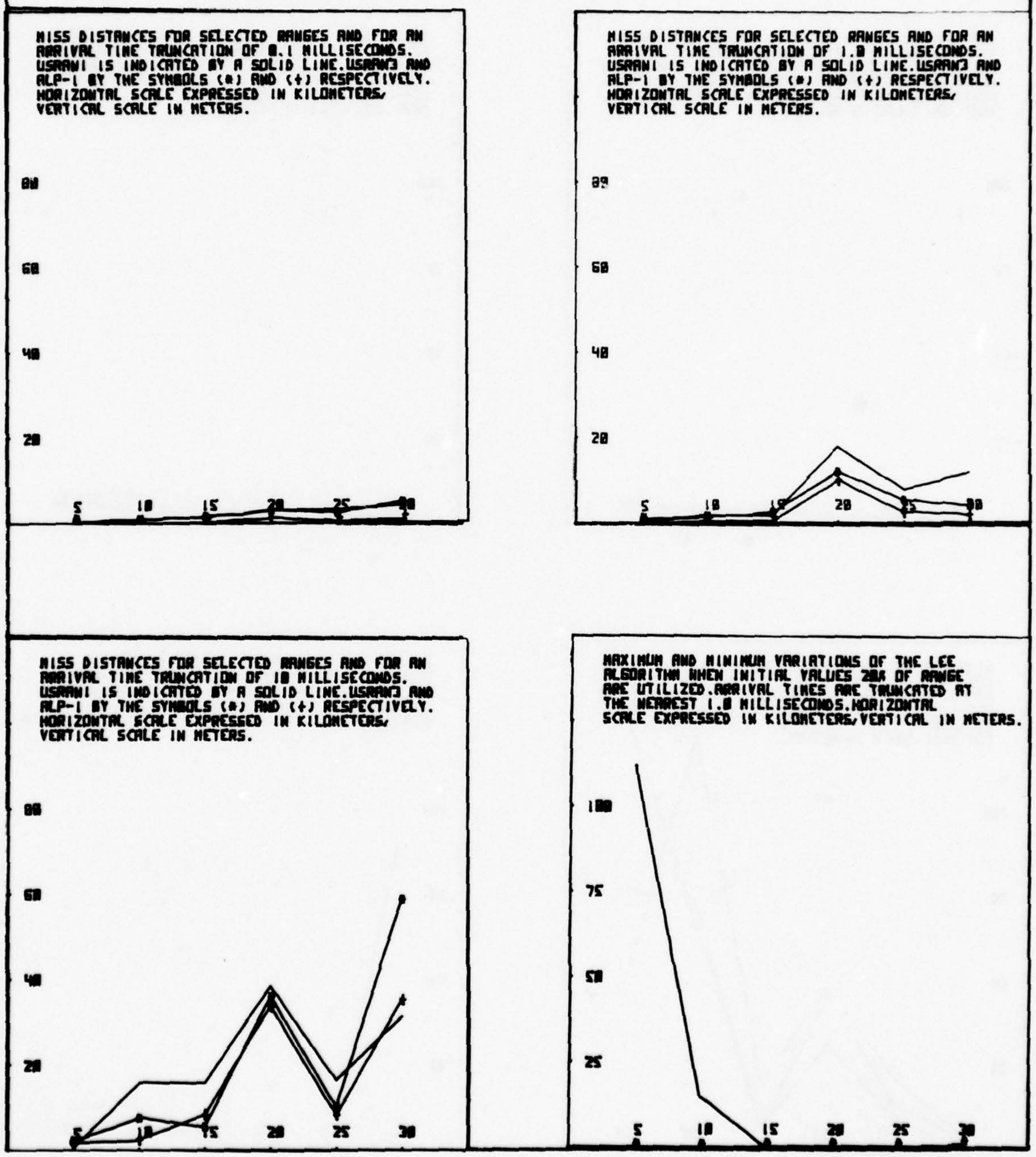
MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 0 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. NO METEOROLOGICAL ERRORS ARE ASSUMED.

FIGURE 2



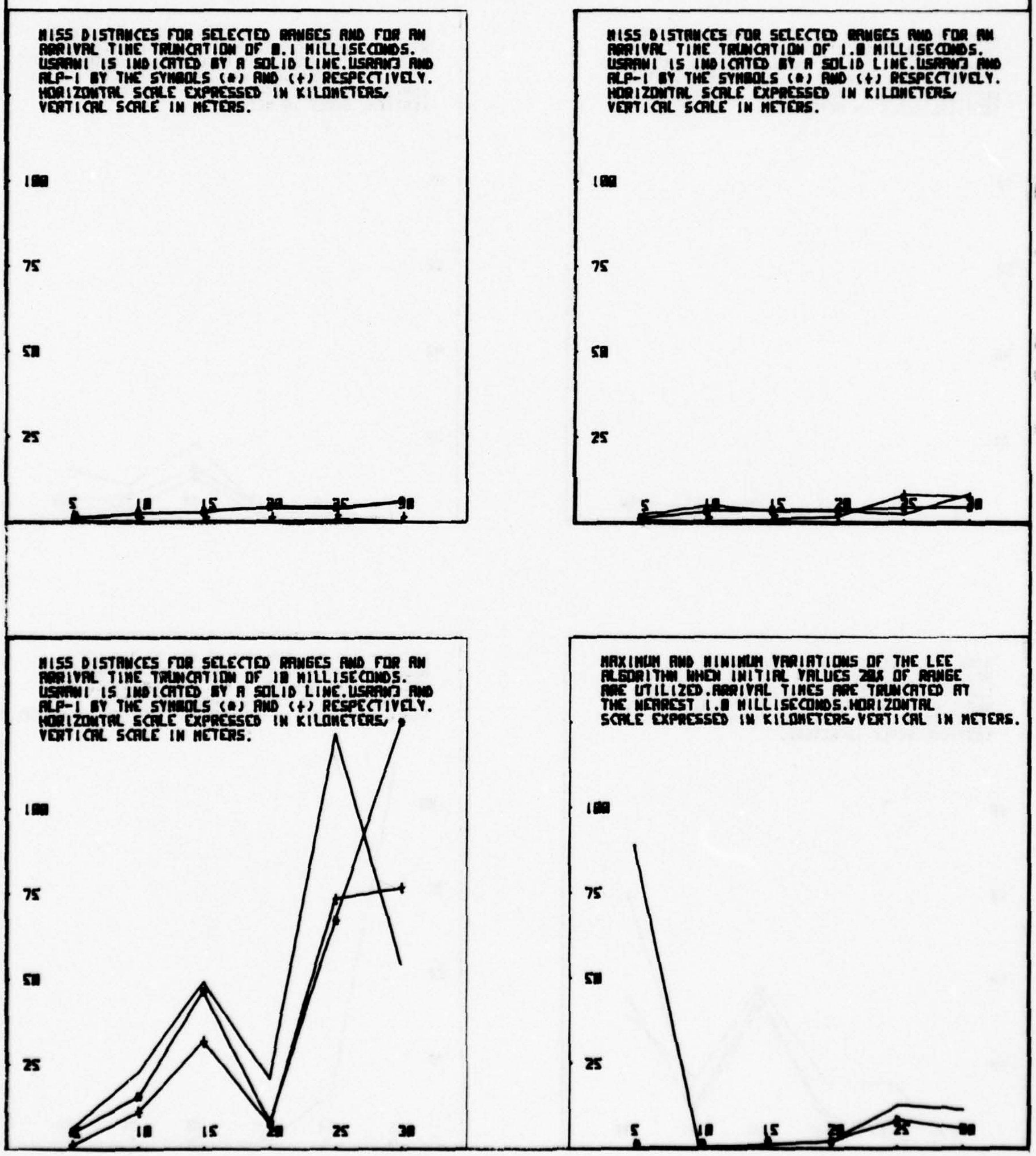
MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 15 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. NO METEOROLOGICAL ERRORS ARE ASSUMED.

FIGURE 3



MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 30 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. NO METEOROLOGICAL ERRORS ARE ASSUMED.

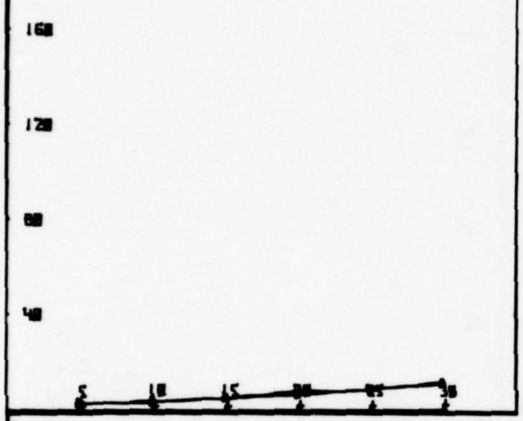
FIGURE 4



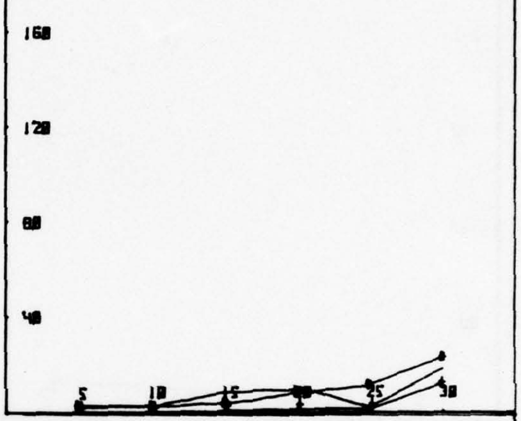
MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 45 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. NO METEOROLOGICAL ERRORS ARE ASSUMED.

FIGURE 5

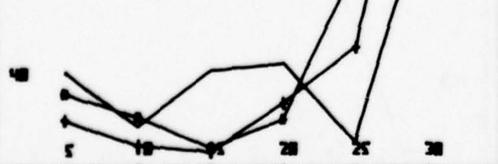
MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 0.1 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.



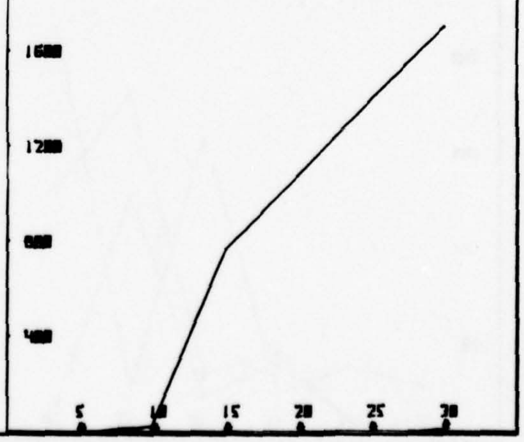
MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 1.0 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.



MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 10 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.

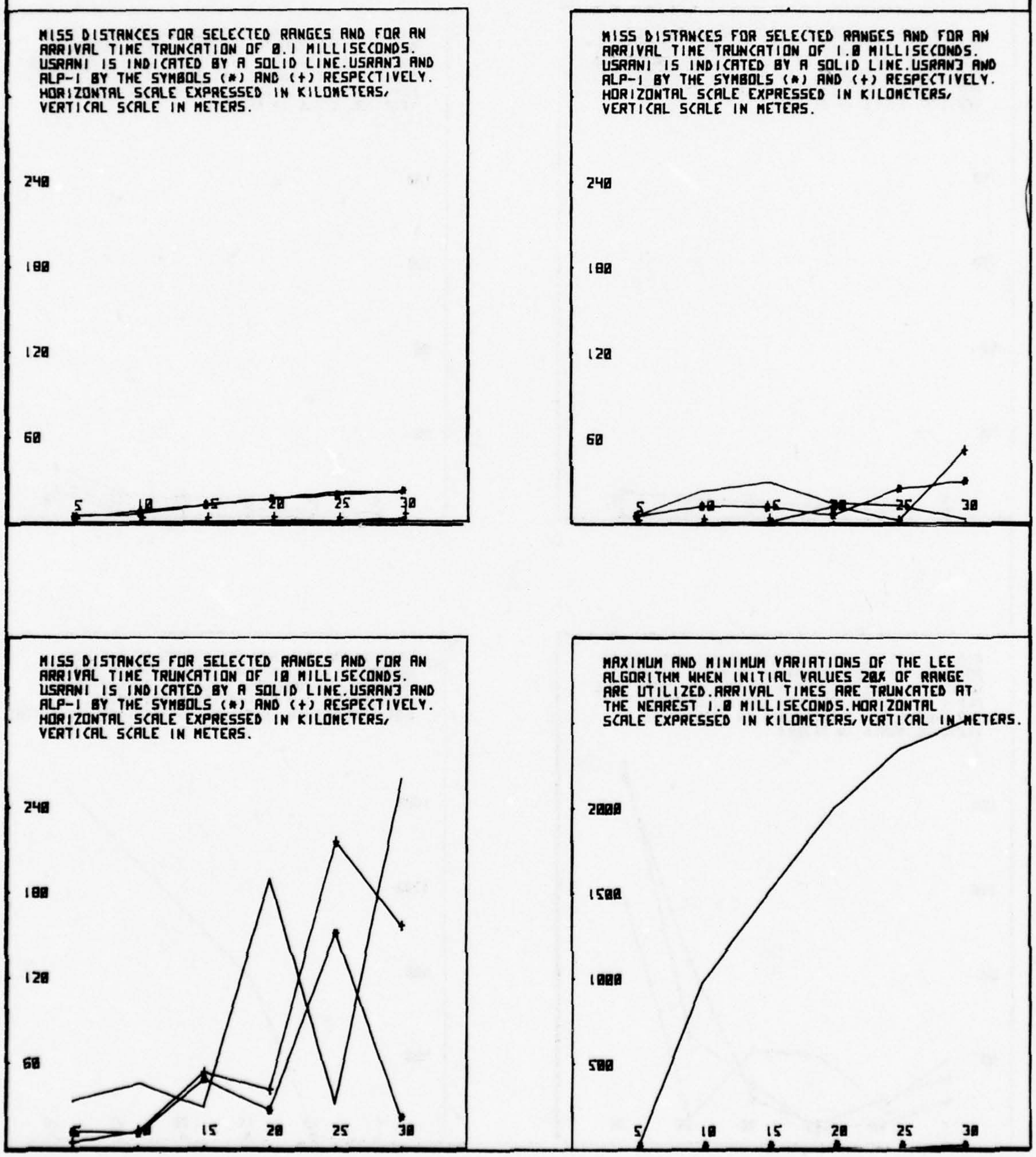


MAXIMUM AND MINIMUM VARIATIONS OF THE LEE ALGORITHM WHEN INITIAL VALUES 20% OF RANGE ARE UTILIZED. ARRIVAL TIMES ARE TRUNCATED AT THE NEAREST 1.0 MILLISECONDS. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL IN METERS.



MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 60 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. NO METEOROLOGICAL ERRORS ARE ASSUMED.

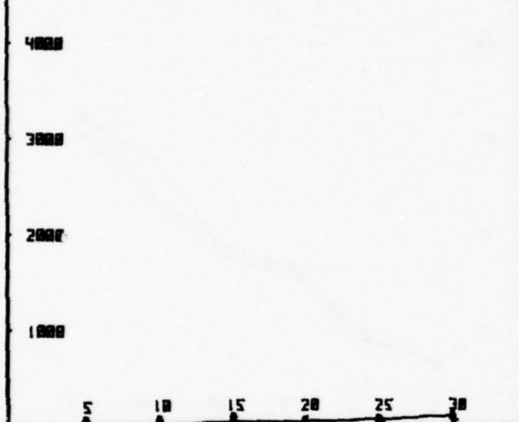
FIGURE 6



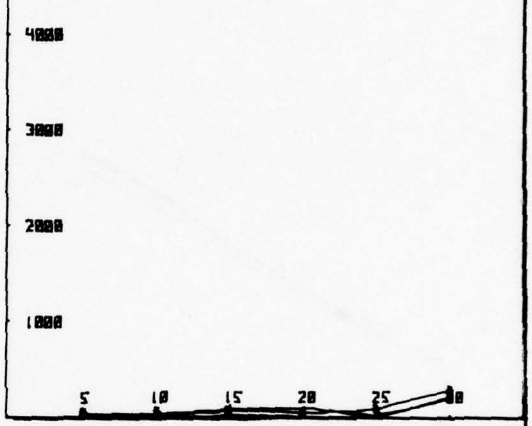
MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 75 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. NO METEOROLOGICAL ERRORS ARE ASSUMED.

FIGURE 7

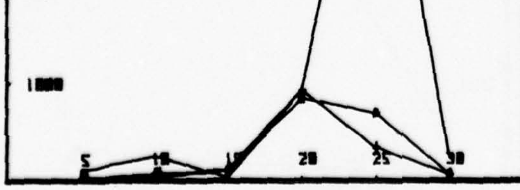
MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 0.1 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.



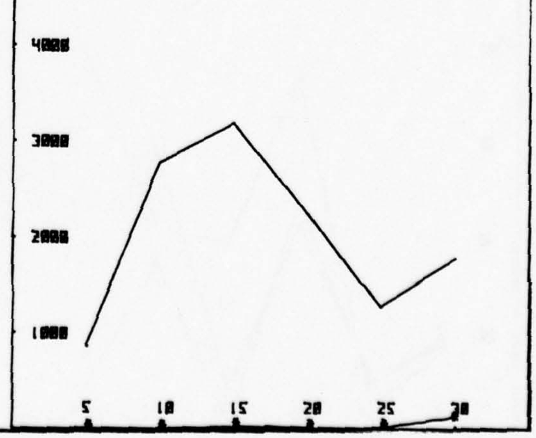
MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 1.0 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.



MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 10 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.

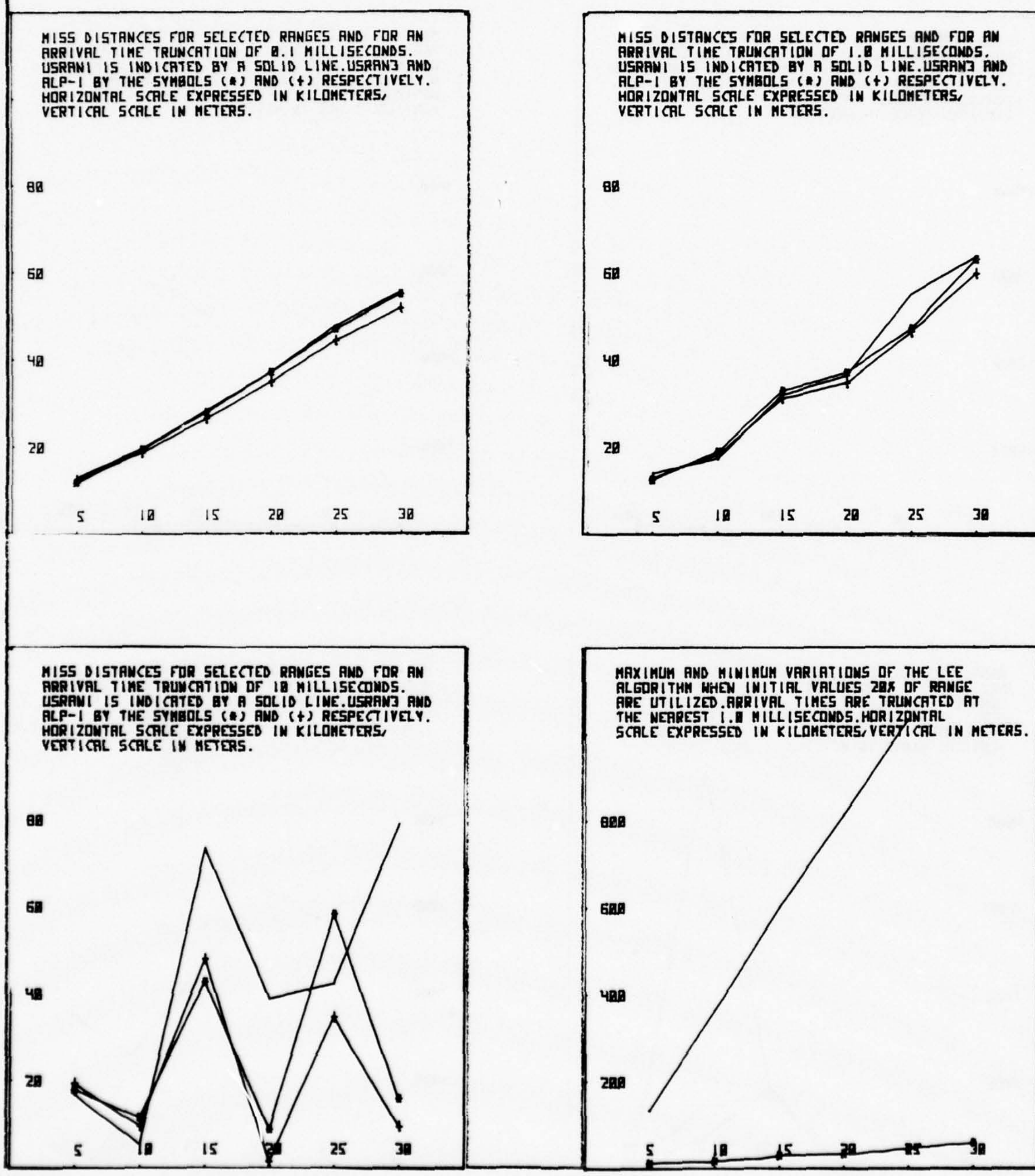


MAXIMUM AND MINIMUM VARIATIONS OF THE LEE ALGORITHM WHEN INITIAL VALUES 20% OF RANGE ARE UTILIZED. ARRIVAL TIMES ARE TRUNCATED AT THE NEAREST 1.0 MILLISECONDS. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL IN METERS.



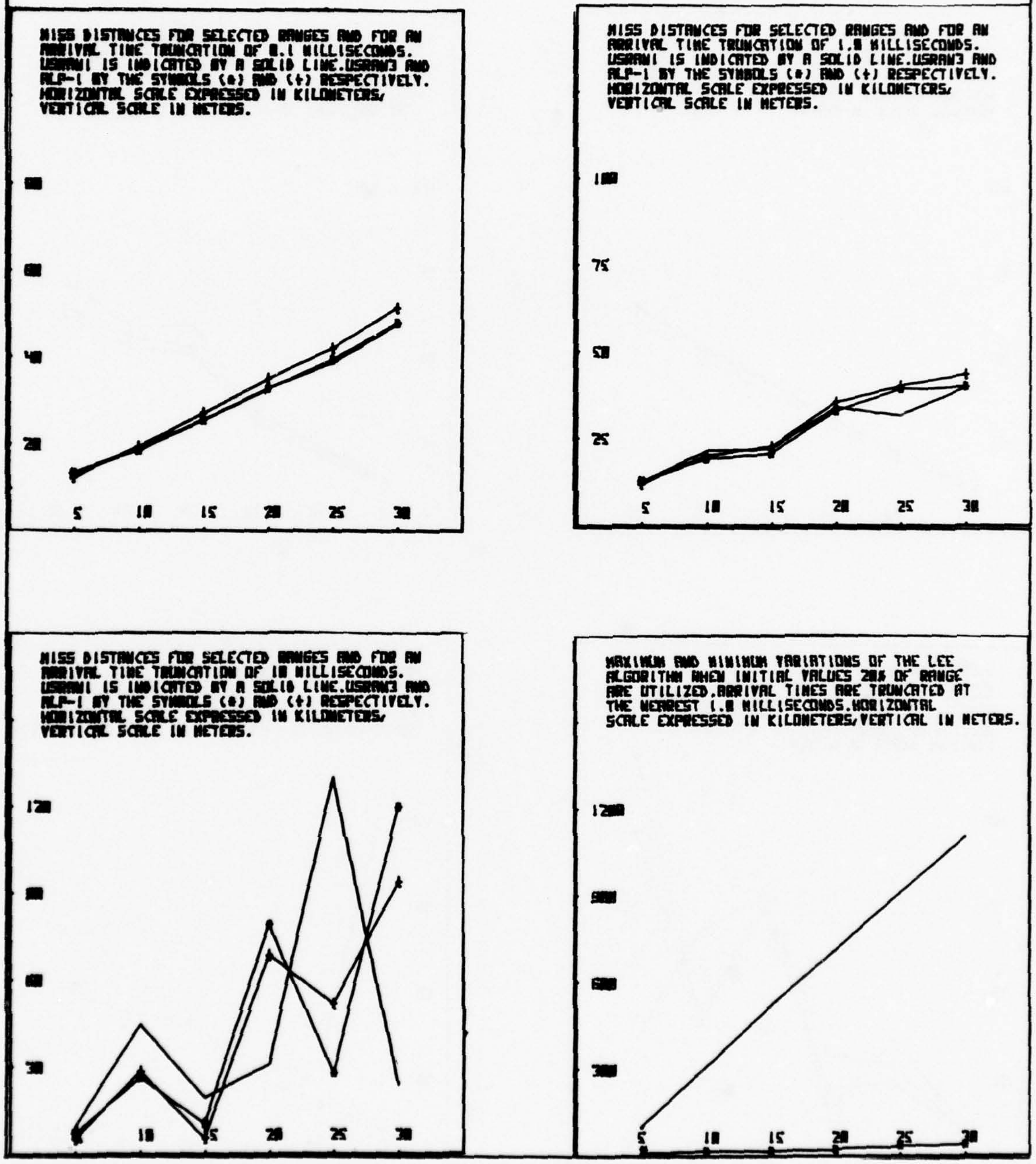
MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 0 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. A TEMPERATURE ERROR OF +1.0 DEGREES KELVIN IS ASSUMED.

FIGURE 8



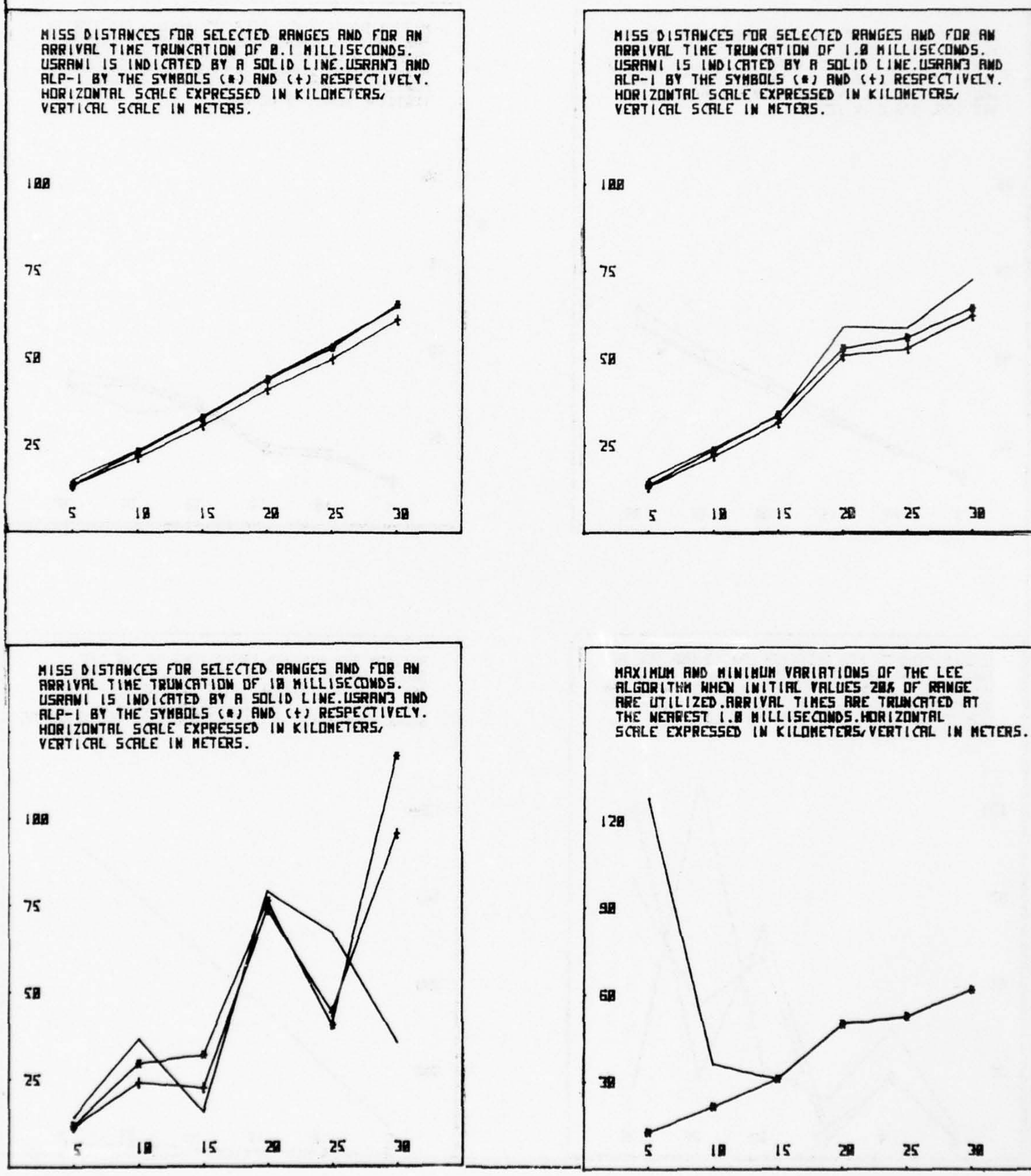
MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 0 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. A TEMPERATURE ERROR OF -1.0 DEGREES KELVIN IS ASSUMED.

FIGURE 9



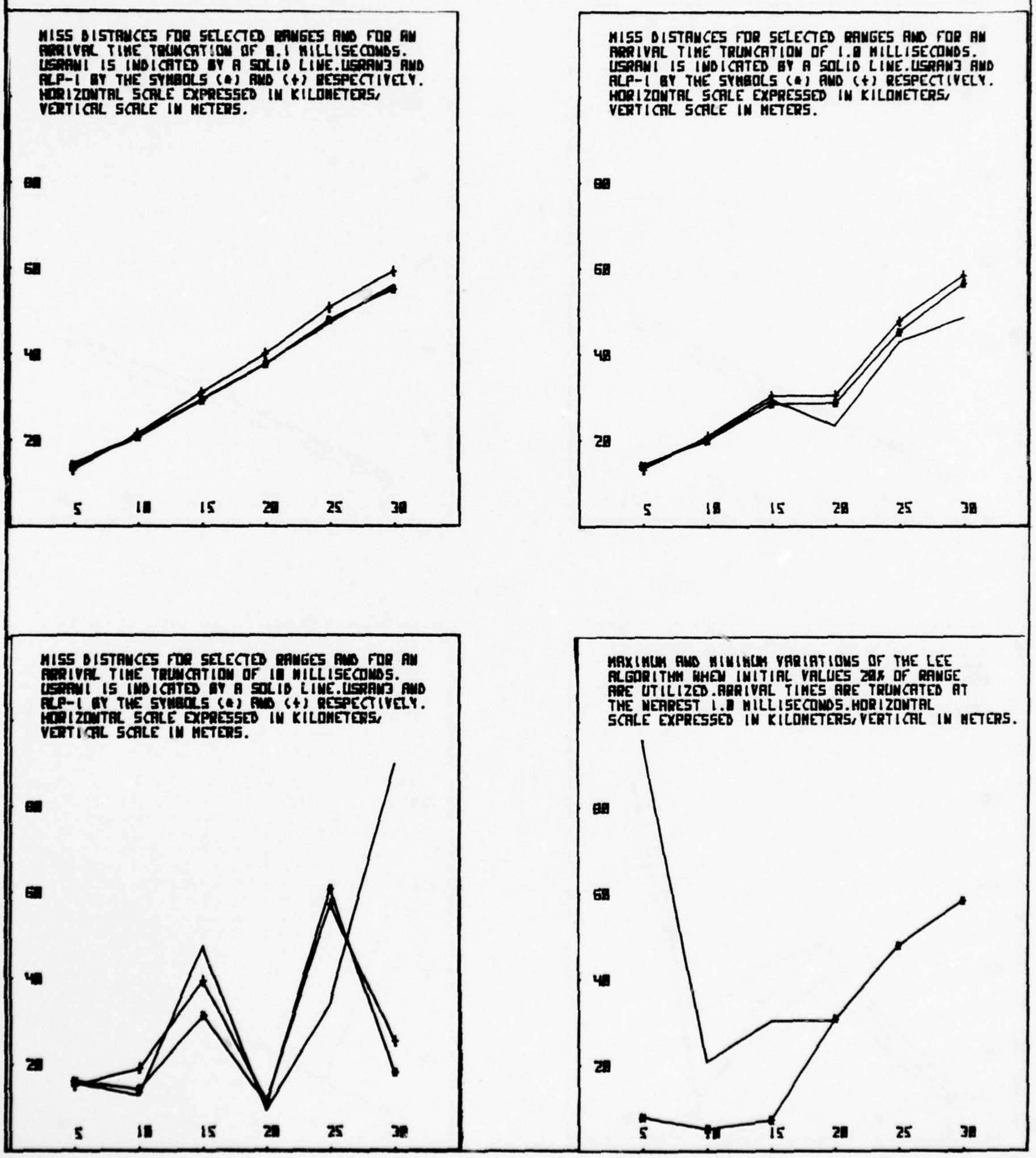
MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 15 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. A TEMPERATURE ERROR OF +1.0 DEGREES KELVIN IS ASSUMED.

FIGURE 10



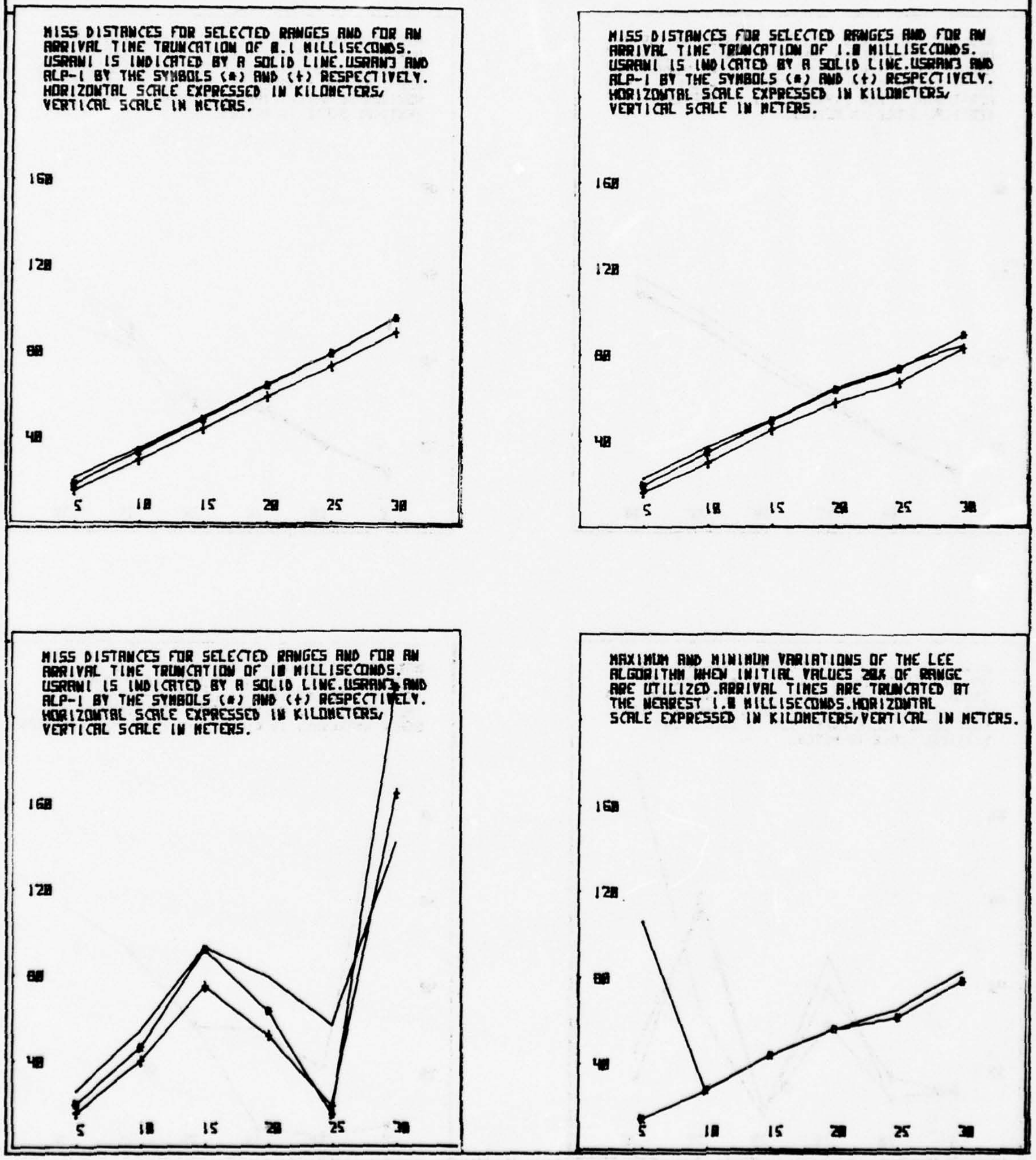
MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 15 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. A TEMPERATURE ERROR OF -1.0 DEGREES KELVIN IS ASSUMED.

FIGURE 11



MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 30 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. A TEMPERATURE ERROR OF +1.0 DEGREES KELVIN IS ASSUMED.

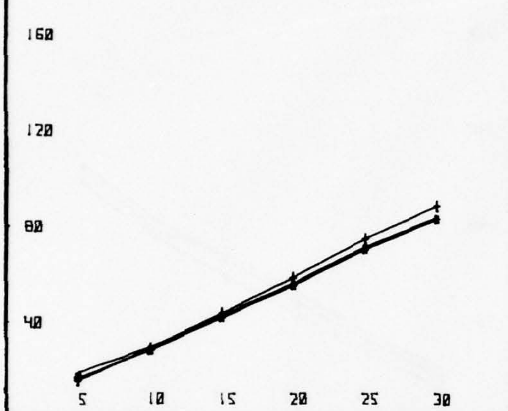
FIGURE 12



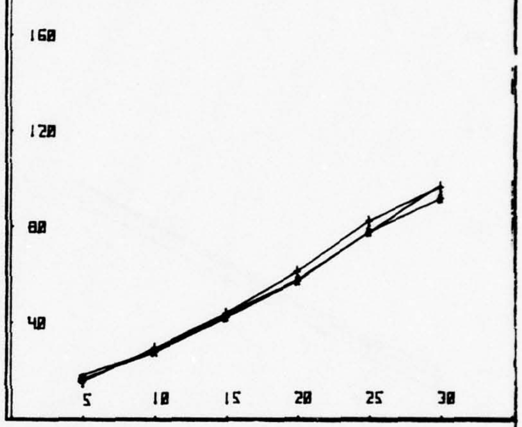
MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 30 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. A TEMPERATURE ERROR OF -1.0 DEGREES KELVIN IS ASSUMED.

FIGURE 13

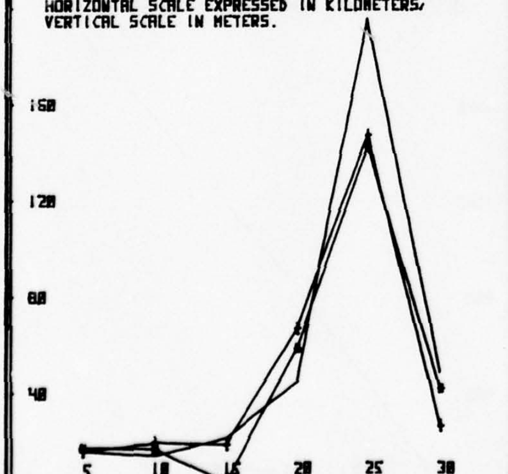
MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 0.1 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.



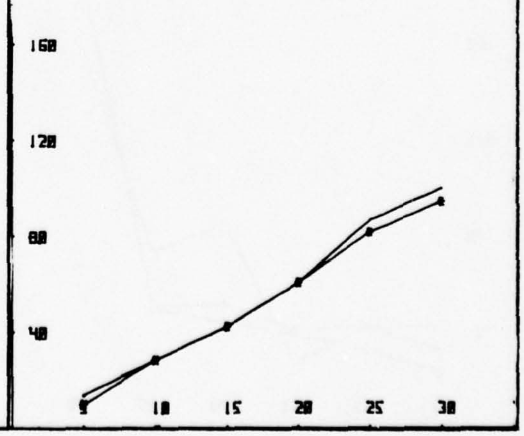
MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 1.0 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.



MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 10 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.



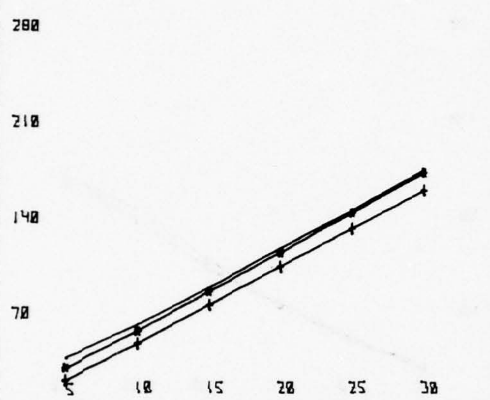
MAXIMUM AND MINIMUM VARIATIONS OF THE LEE ALGORITHM WHEN INITIAL VALUES 20% OF RANGE ARE UTILIZED. ARRIVAL TIMES ARE TRUNCATED AT THE NEAREST 1.0 MILLISECONDS. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL IN METERS.



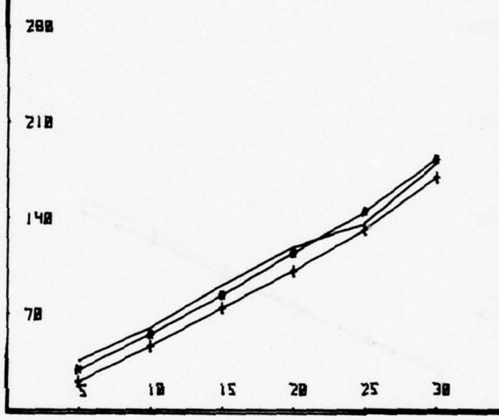
MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 45 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. A TEMPERATURE ERROR OF +1.0 DEGREES KELVIN IS ASSUMED.

FIGURE 14

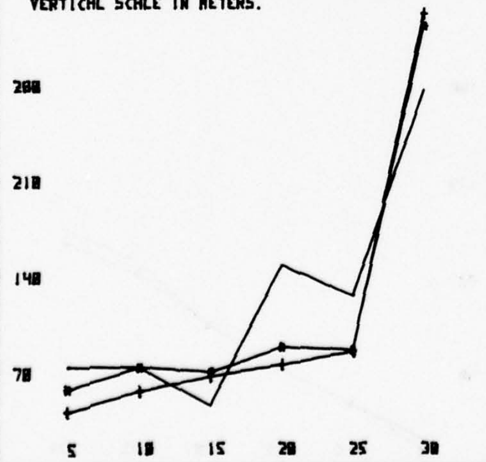
MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 0.1 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS/ VERTICAL SCALE IN METERS.



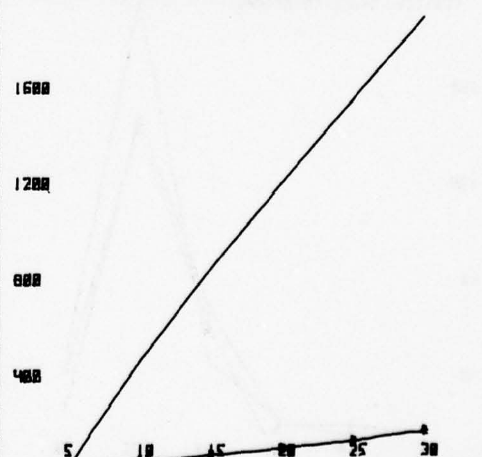
MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 1.0 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS/ VERTICAL SCALE IN METERS.



MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 10 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS/ VERTICAL SCALE IN METERS.

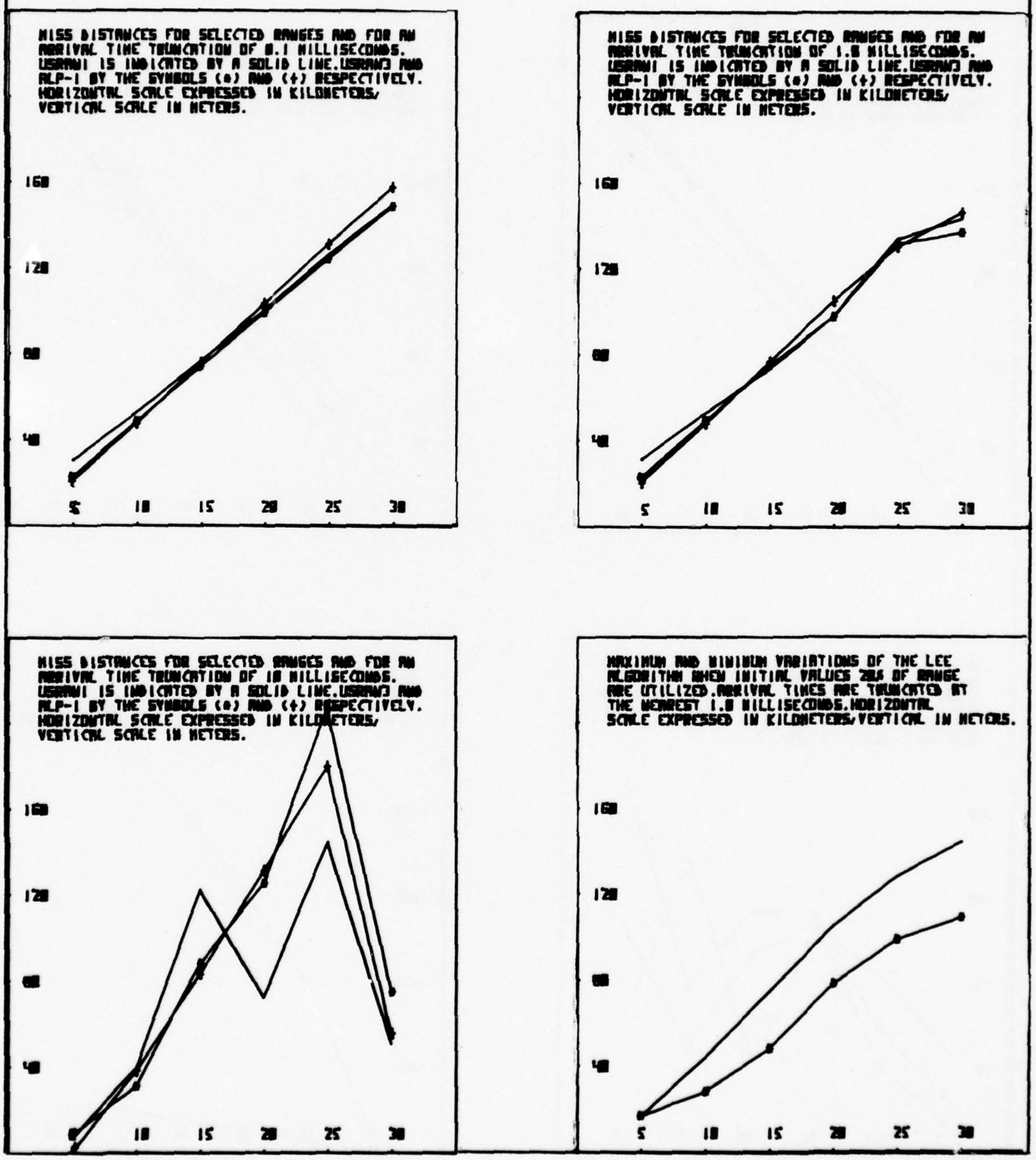


MAXIMUM AND MINIMUM VARIATIONS OF THE LEE ALGORITHM WHEN INITIAL VALUES 20% OF RANGE ARE UTILIZED. ARRIVAL TIMES ARE TRUNCATED AT THE NEAREST 1.0 MILLISECONDS. HORIZONTAL SCALE EXPRESSED IN KILOMETERS/VERTICAL IN METERS.



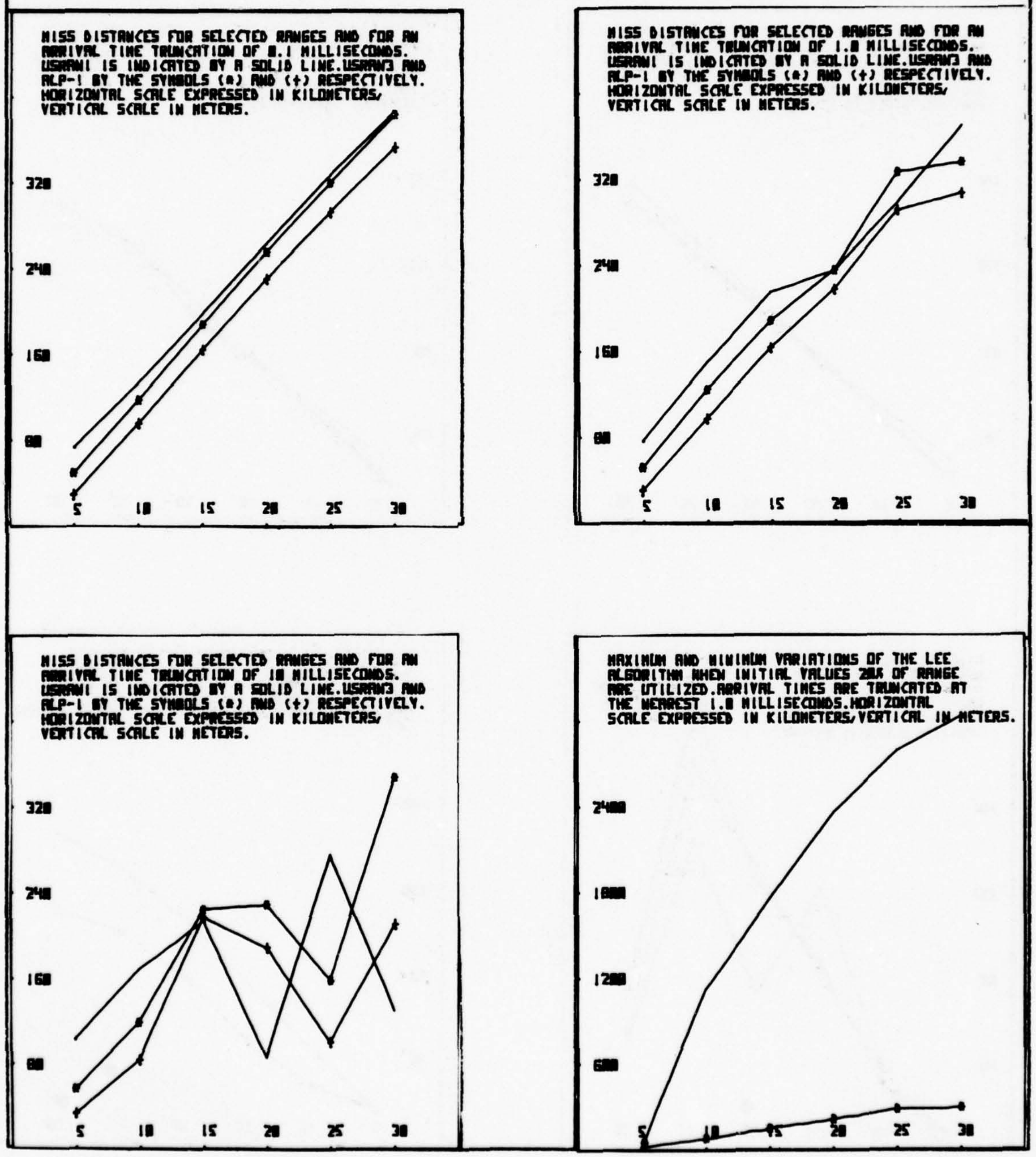
MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 45 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. A TEMPERATURE ERROR OF -1.0 DEGREES KELVIN IS ASSUMED.

FIGURE 15



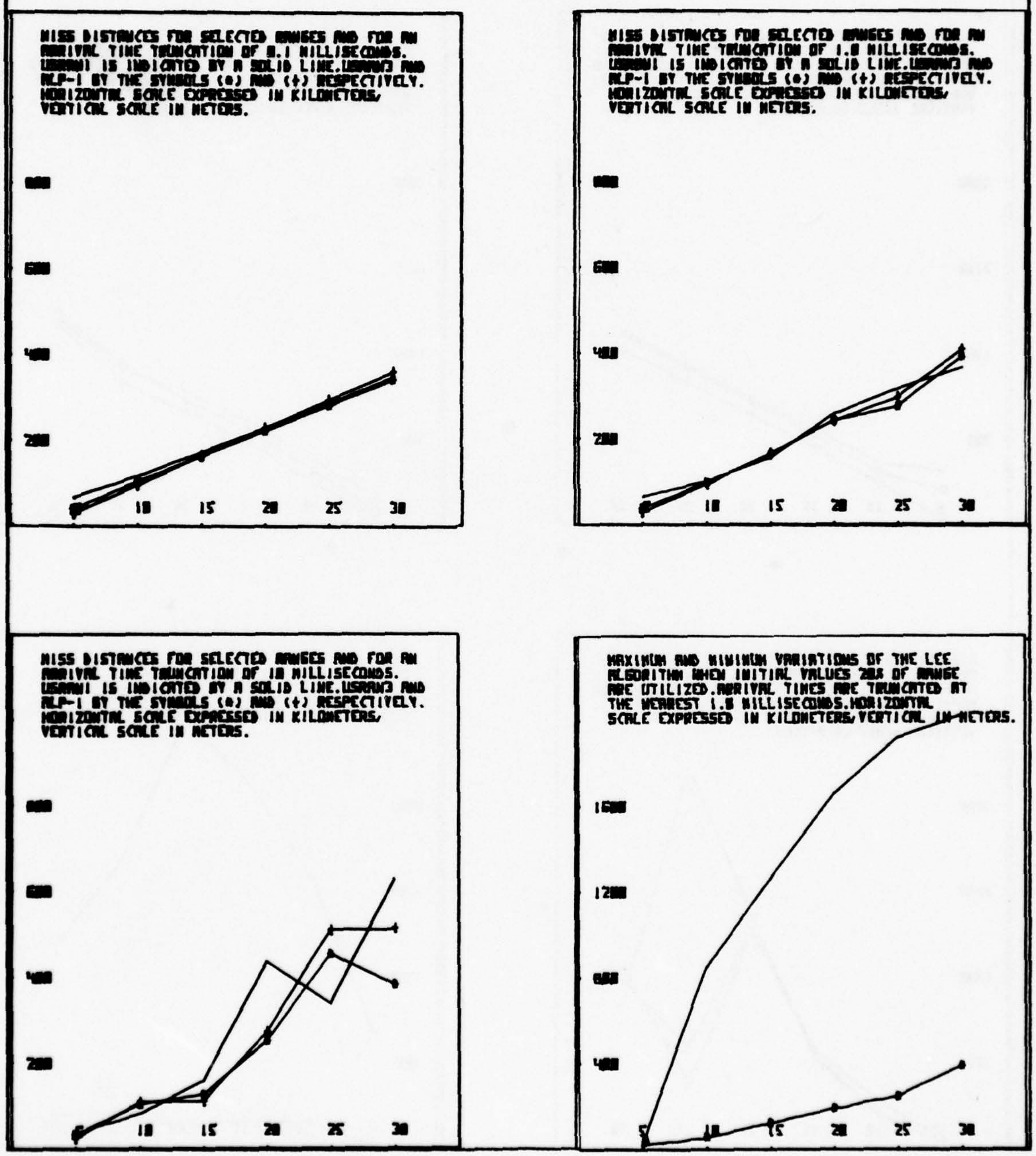
MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 60 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. A TEMPERATURE ERROR OF +1.0 DEGREES KELVIN IS ASSUMED.

FIGURE 16



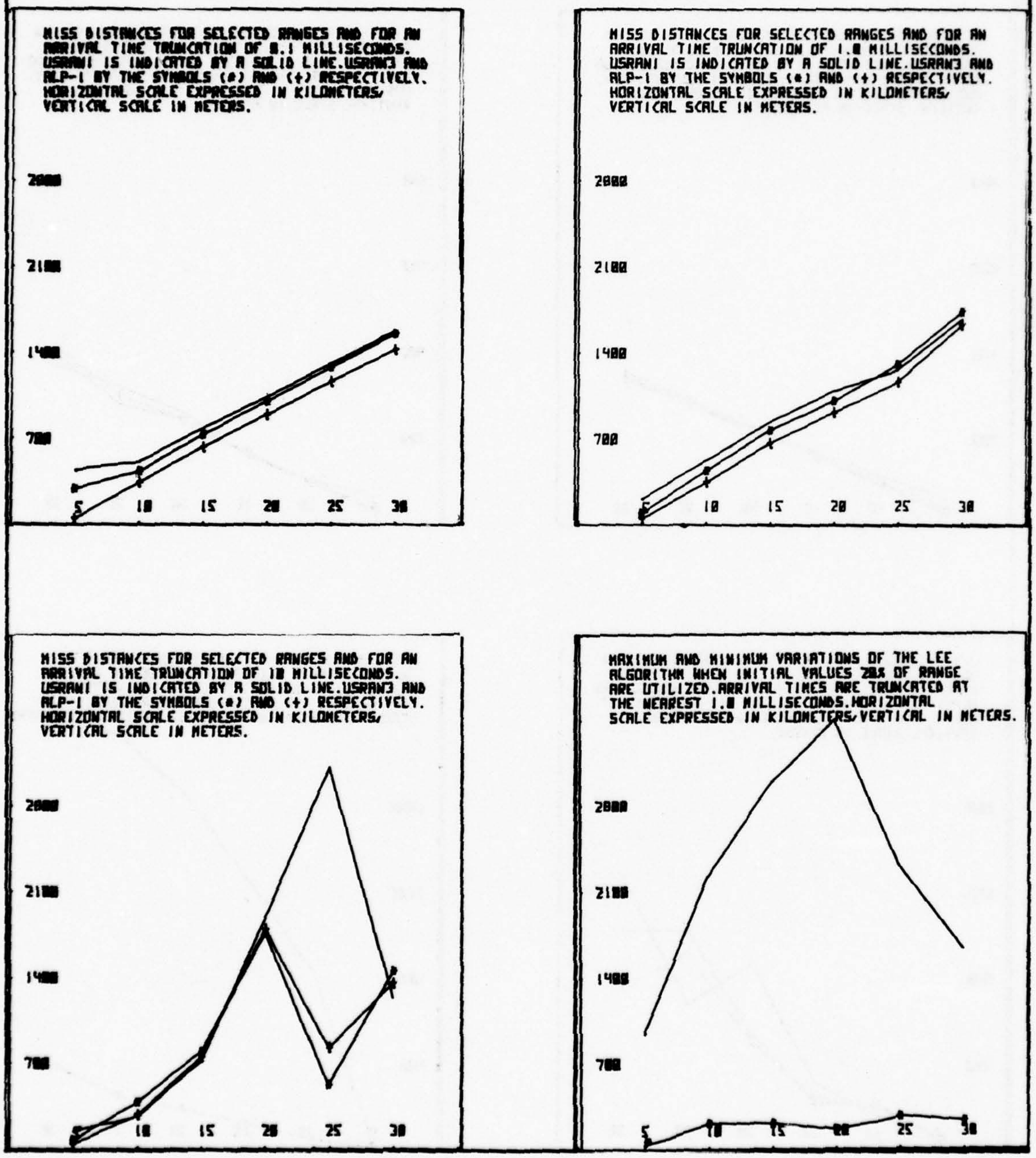
MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 60 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. A TEMPERATURE ERROR OF -1.0 DEGREES KELVIN IS ASSUMED.

FIGURE 17



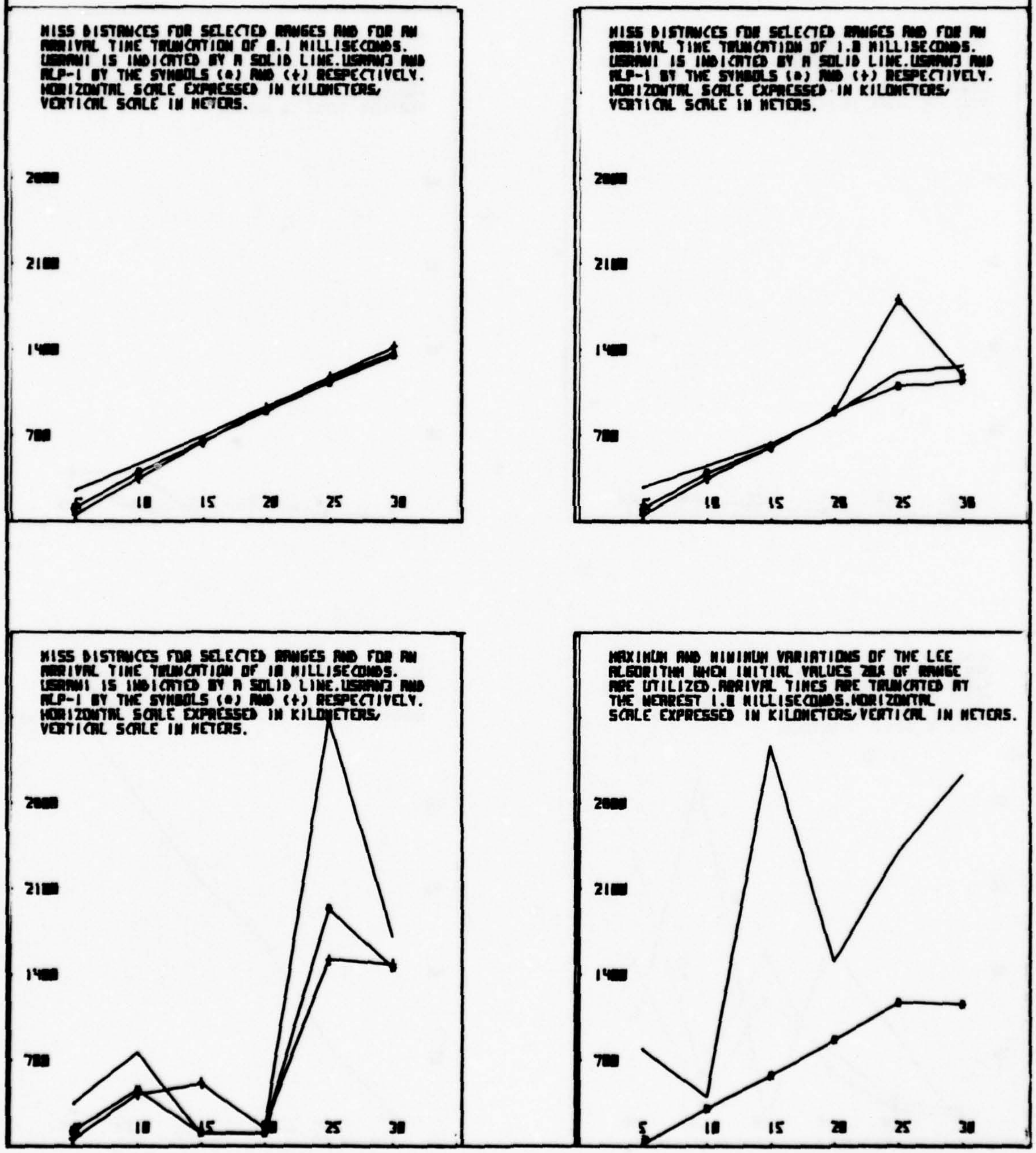
MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 75 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. A TEMPERATURE ERROR OF +1.0 DEGREES KELVIN IS ASSUMED.

FIGURE 18



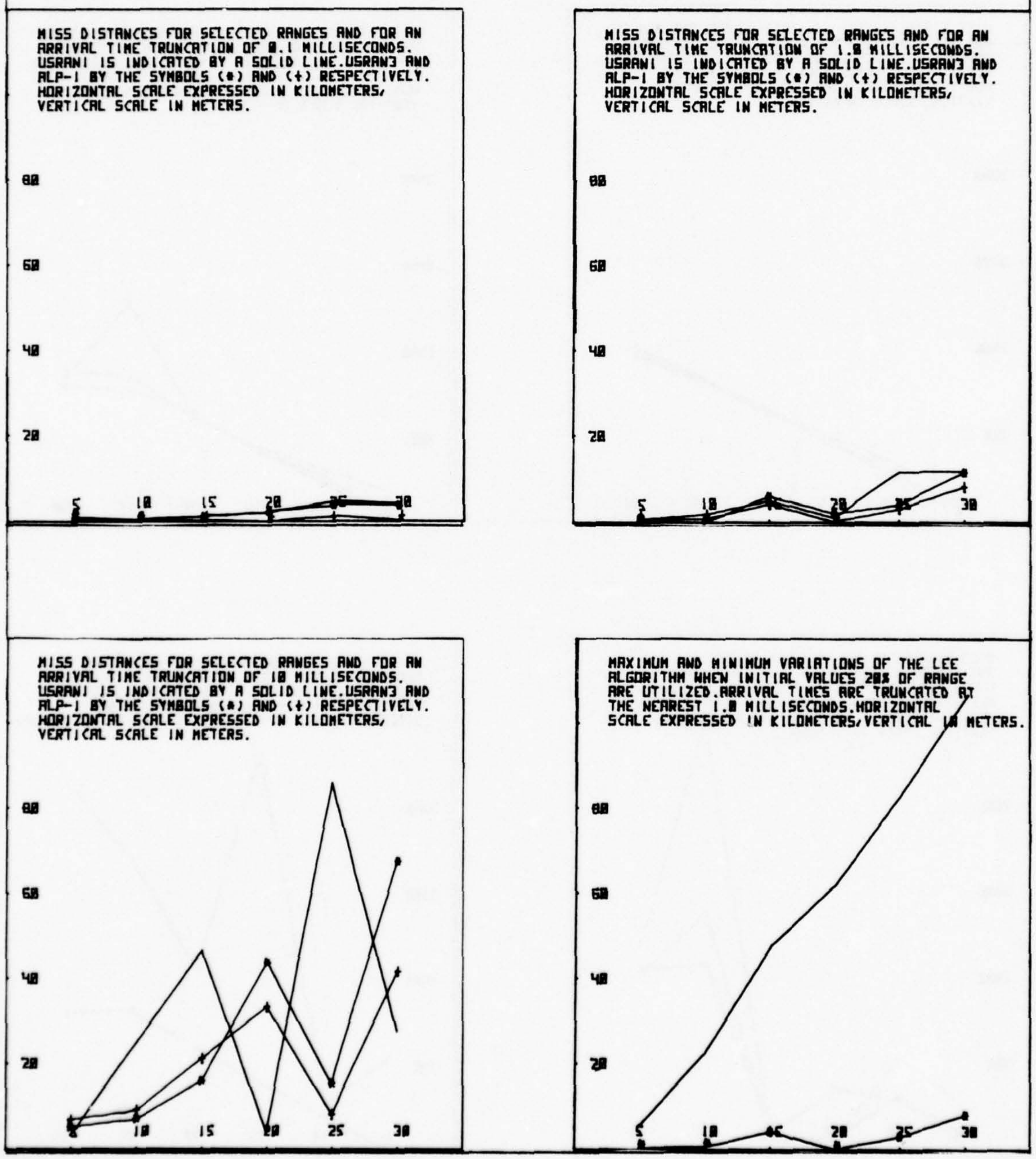
MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 75 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. A TEMPERATURE ERROR OF -1.0 DEGREES KELVIN IS ASSUMED.

FIGURE 19



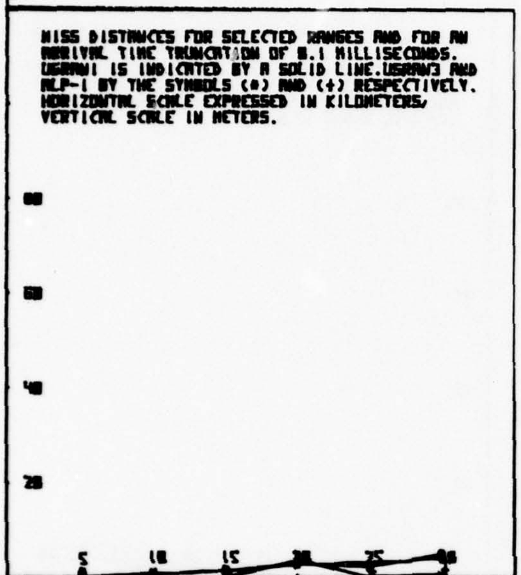
MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 0 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. IN ADDITION, AN ERROR OF ONE METER PER SECOND IS ASSUMED IN THE SOUTH WIND COMPONENT.

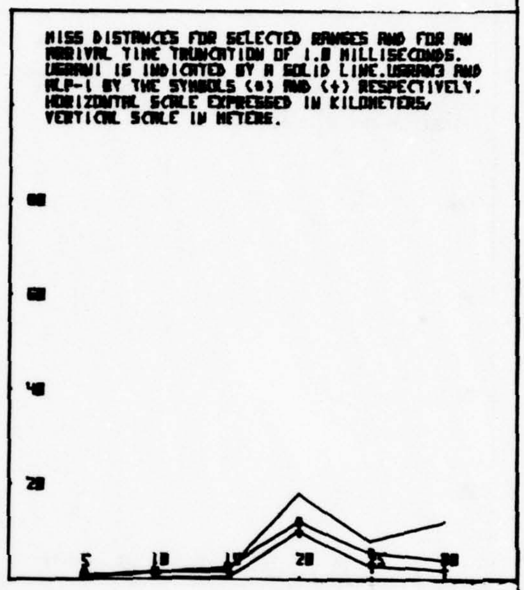
FIGURE 20

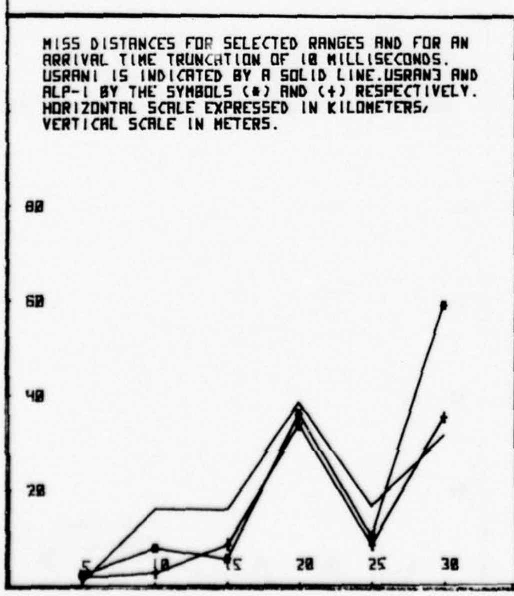


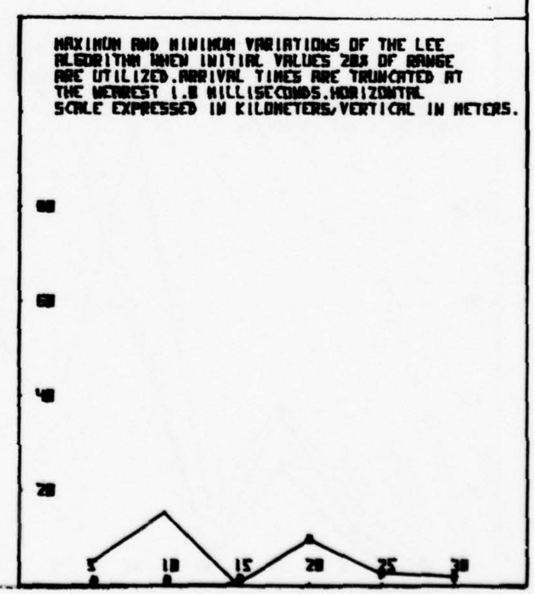
MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 15 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. IN ADDITION, AN ERROR OF ONE METER PER SECOND IS ASSUMED IN THE SOUTH WIND COMPONENT.

FIGURE 21









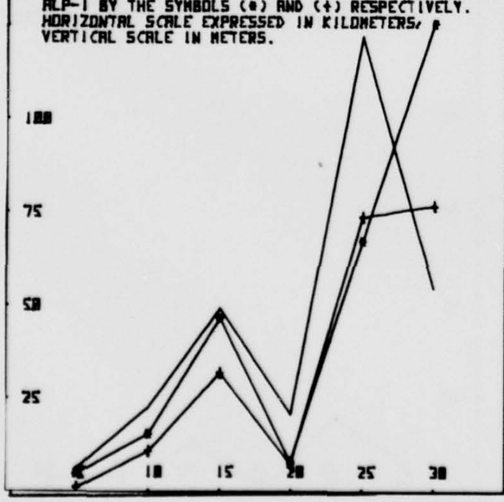
MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 30 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. IN ADDITION, AN ERROR OF ONE METER PER SECOND IS ASSUMED IN THE SOUTH WIND COMPONENT.

FIGURE 22

MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 10 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.

MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 1.0 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.

MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 10 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.



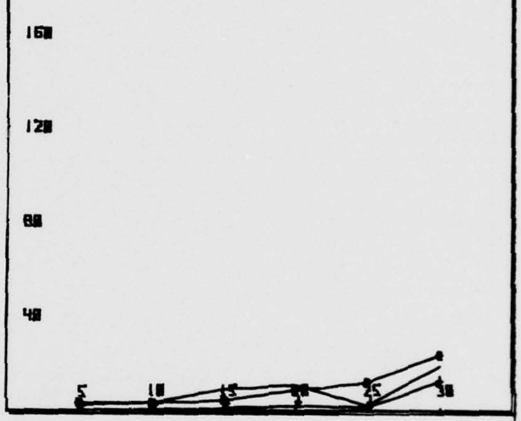
MAXIMUM AND MINIMUM VARIATIONS OF THE LEE ALGORITHM WHEN INITIAL VALUES 20% OF RANGE ARE UTILIZED. ARRIVAL TIMES ARE TRUNCATED AT THE NEAREST 1.0 MILLISECONDS. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL IN METERS.

MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 45 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. IN ADDITION/AN ERROR OF ONE METER PER SECOND IS ASSUMED IN THE SOUTH WIND COMPONENT.

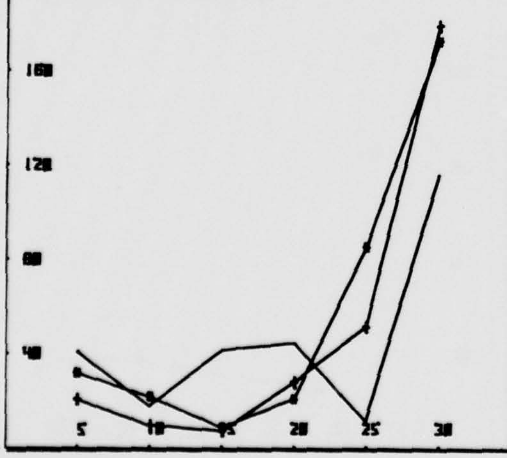
FIGURE 23

MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 0.1 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE.USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS/ VERTICAL SCALE IN METERS.

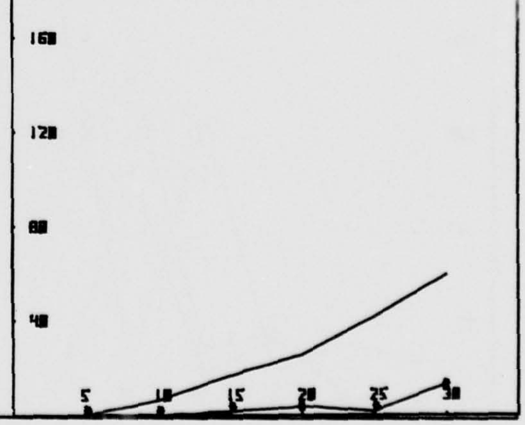
MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 1.0 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE.USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS/ VERTICAL SCALE IN METERS.



MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 10 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE.USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS/ VERTICAL SCALE IN METERS.



MAXIMUM AND MINIMUM VARIATIONS OF THE LEE ALGORITHM WHEN INITIAL VALUES 20% OF RANGE ARE UTILIZED. ARRIVAL TIMES ARE TRUNCATED AT THE NEAREST 1.0 MILLISECONDS. HORIZONTAL SCALE EXPRESSED IN KILOMETERS/VERTICAL IN METERS.

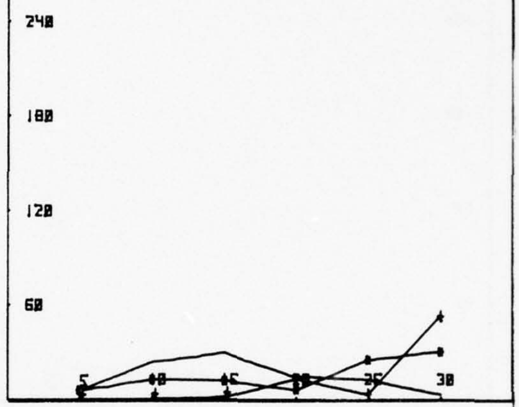


MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 60 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. IN ADDITION, AN ERROR OF ONE METER PER SECOND IS ASSUMED IN THE SOUTH WIND COMPONENT.

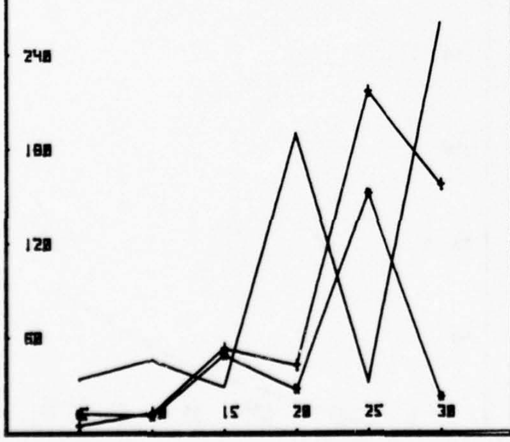
FIGURE 24

MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 0.1 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.

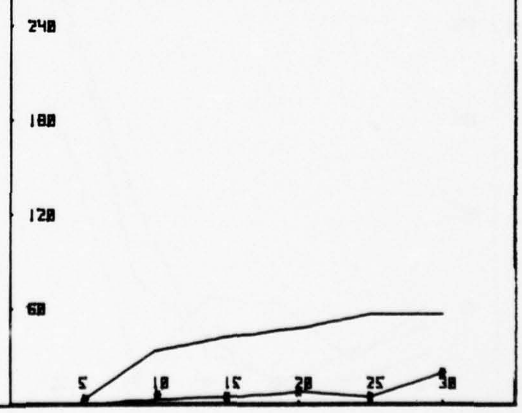
MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 1.0 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.



MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 10 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.

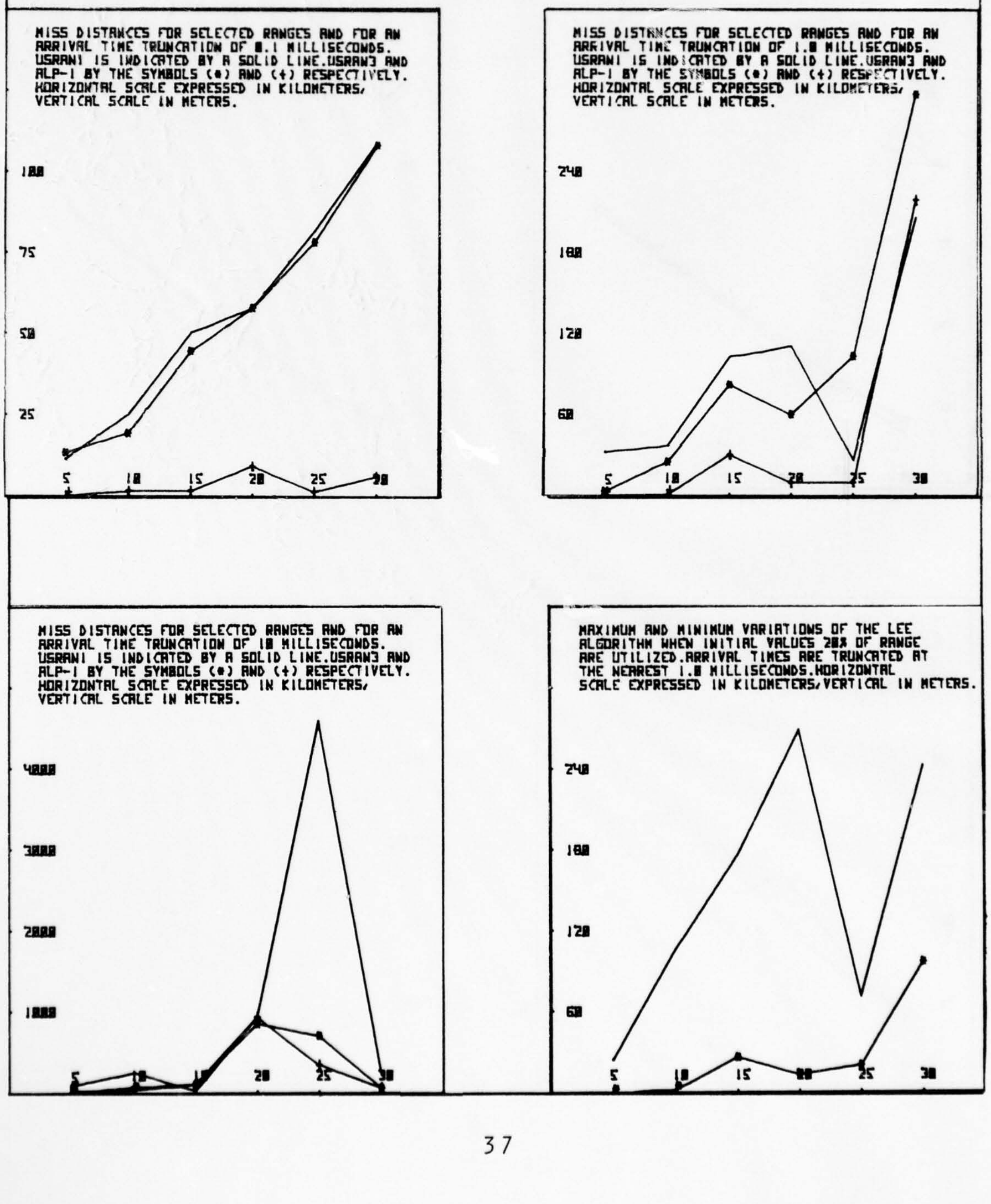


MAXIMUM AND MINIMUM VARIATIONS OF THE LEE ALGORITHM WHEN INITIAL VALUES 20% OF RANGE ARE UTILIZED. ARRIVAL TIMES ARE TRUNCATED AT THE NEAREST 1.0 MILLISECONDS. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL IN METERS.



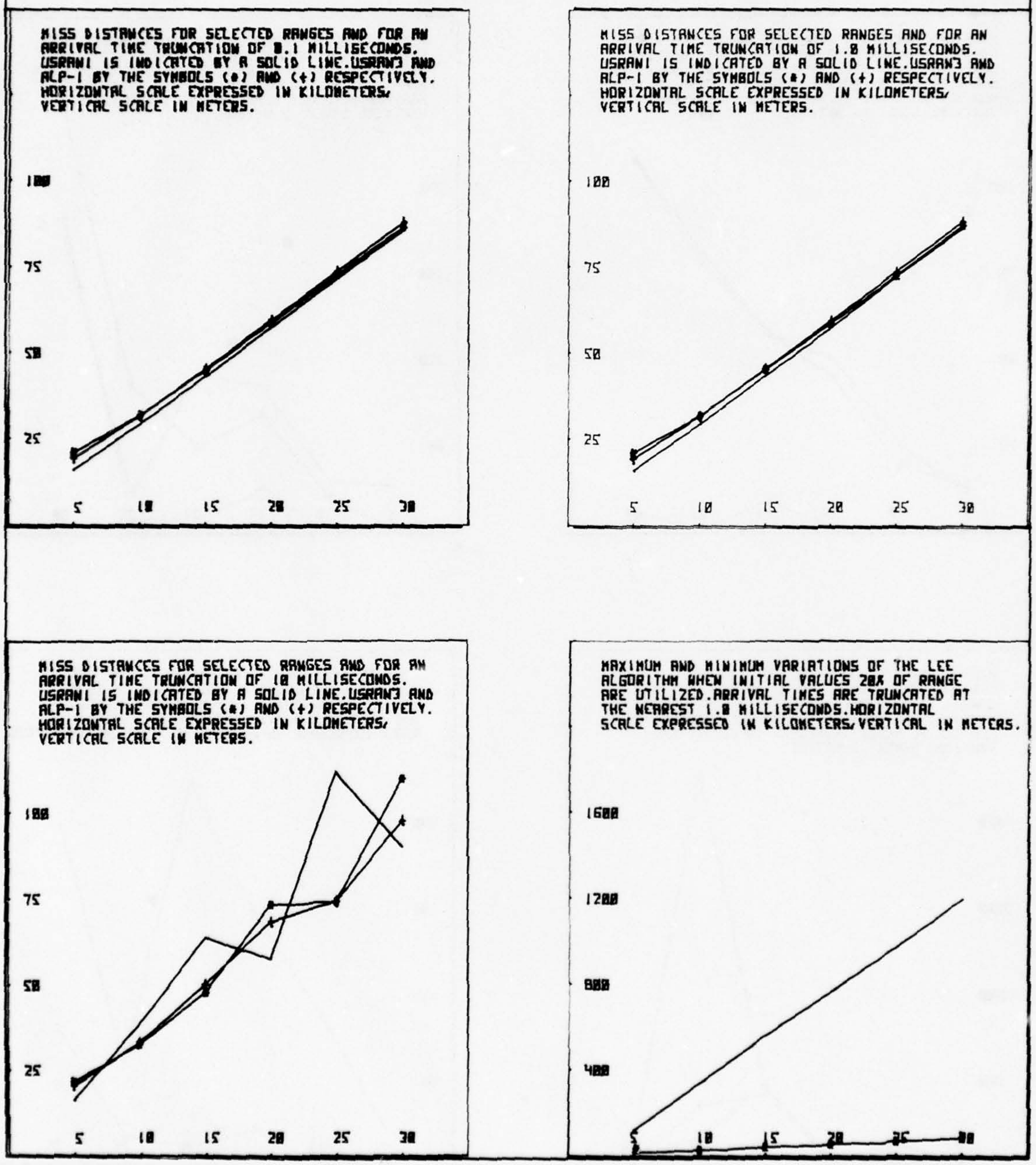
MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 75 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. IN ADDITION, AN ERROR OF ONE METER PER SECOND IS ASSUMED IN THE SOUTH WIND COMPONENT.

FIGURE 25



MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 0 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. IN ADDITION, AN ERROR OF ONE METER PER SECOND IS ASSUMED IN THE WEST WIND COMPONENT.

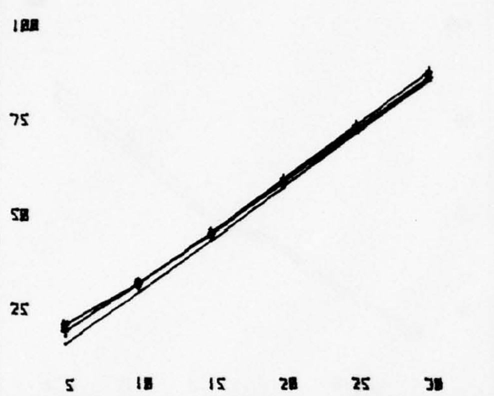
FIGURE 26



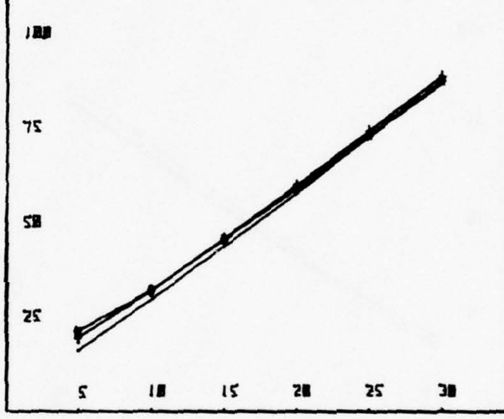
MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 0 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. IN ADDITION, AN ERROR OF ONE METER PER SECOND IS ASSUMED IN THE EAST WIND COMPONENT.

FIGURE 27

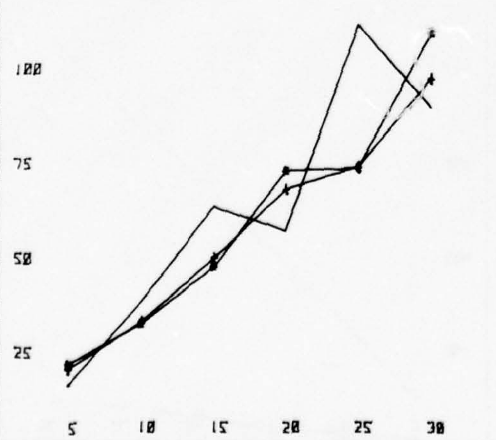
MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 0.1 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS/ VERTICAL SCALE IN METERS.



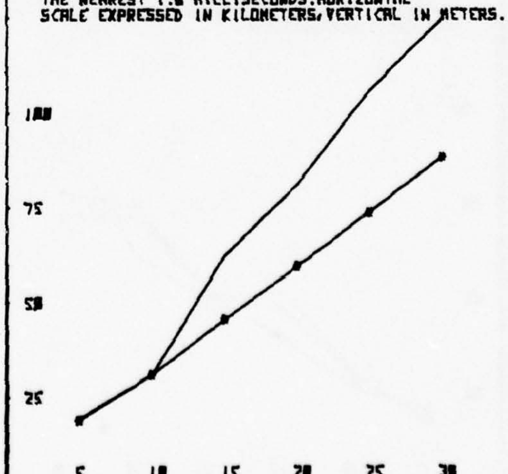
MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 1.0 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS/ VERTICAL SCALE IN METERS.



MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 10 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS/ VERTICAL SCALE IN METERS.



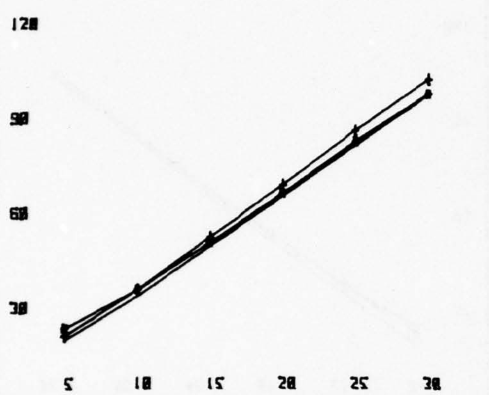
MAXIMUM AND MINIMUM VARIATIONS OF THE LEE ALGORITHM WHEN INITIAL VALUES 20% OF RANGE ARE UTILIZED. ARRIVAL TIMES ARE TRUNCATED AT THE NEAREST 1.0 MILLISECONDS. HORIZONTAL SCALE EXPRESSED IN KILOMETERS/ VERTICAL SCALE IN METERS.



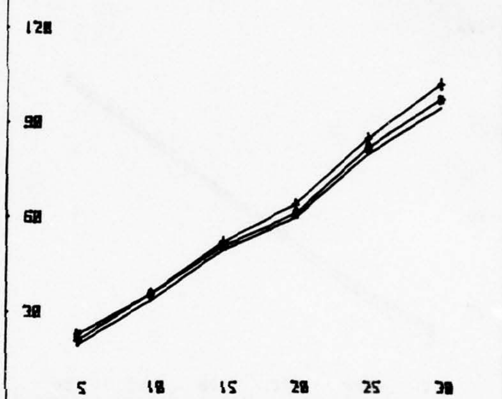
MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 15 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. IN ADDITION, AN ERROR OF ONE METER PER SECOND IS ASSUMED IN THE WEST WIND COMPONENT.

FIGURE 28

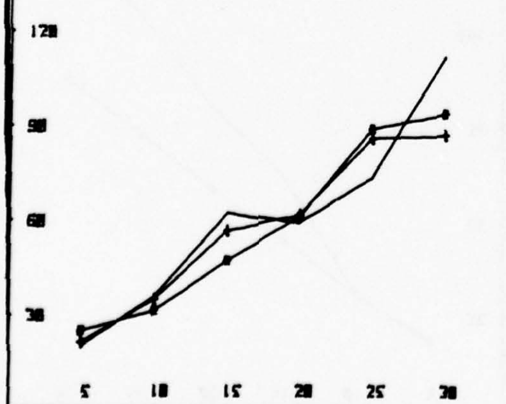
MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 0.1 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.



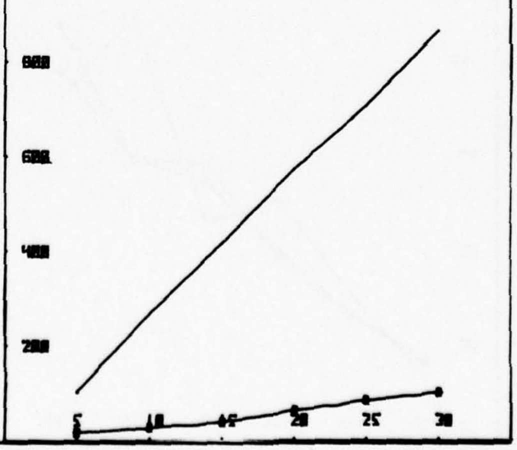
MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 1.0 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.



MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 10 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.

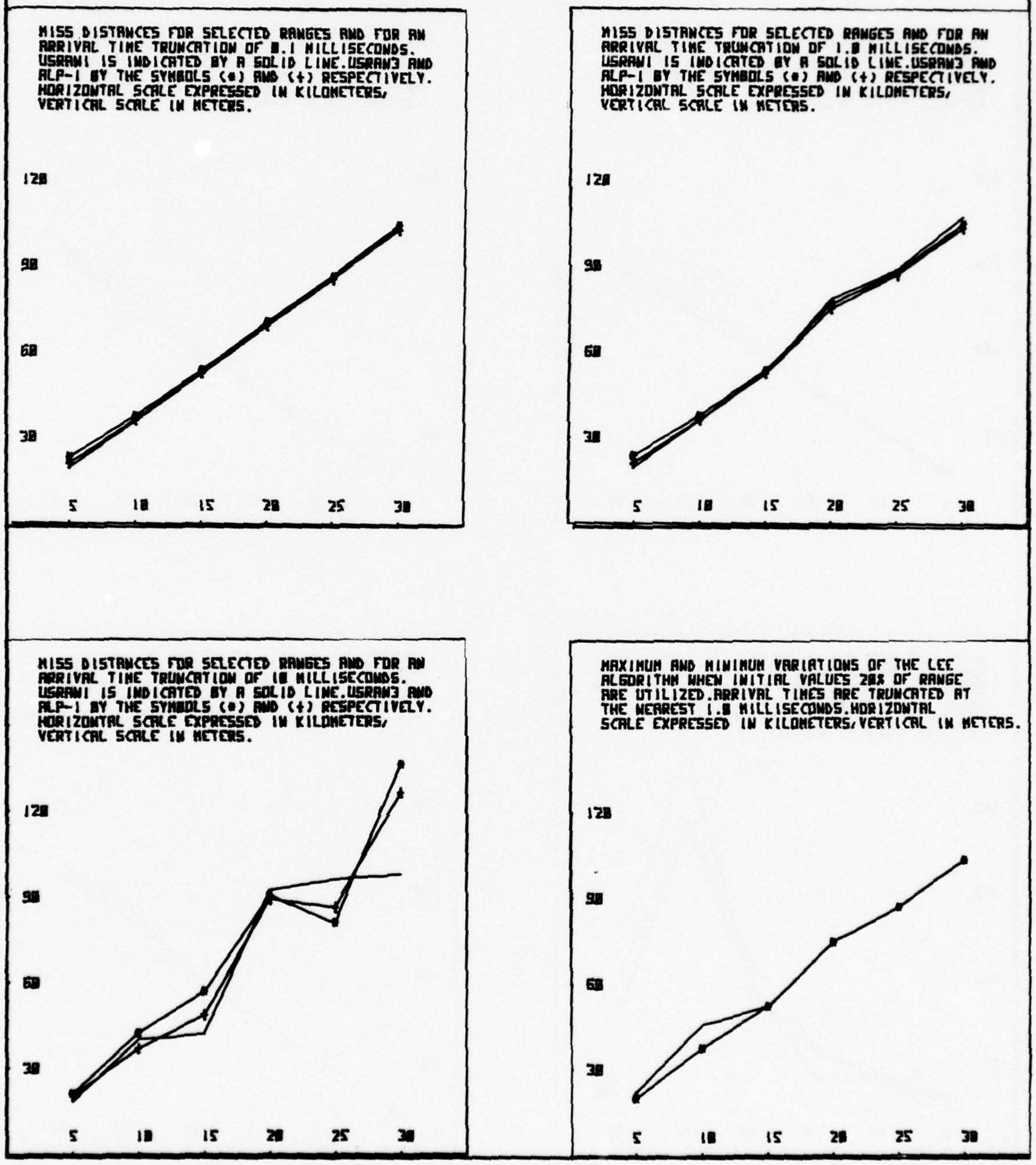


MAXIMUM AND MINIMUM VARIATIONS OF THE LEE ALGORITHM WHEN INITIAL VALUES 20% OF RANGE ARE UTILIZED. ARRIVAL TIMES ARE TRUNCATED AT THE NEAREST 1.0 MILLISECONDS. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL IN METERS.



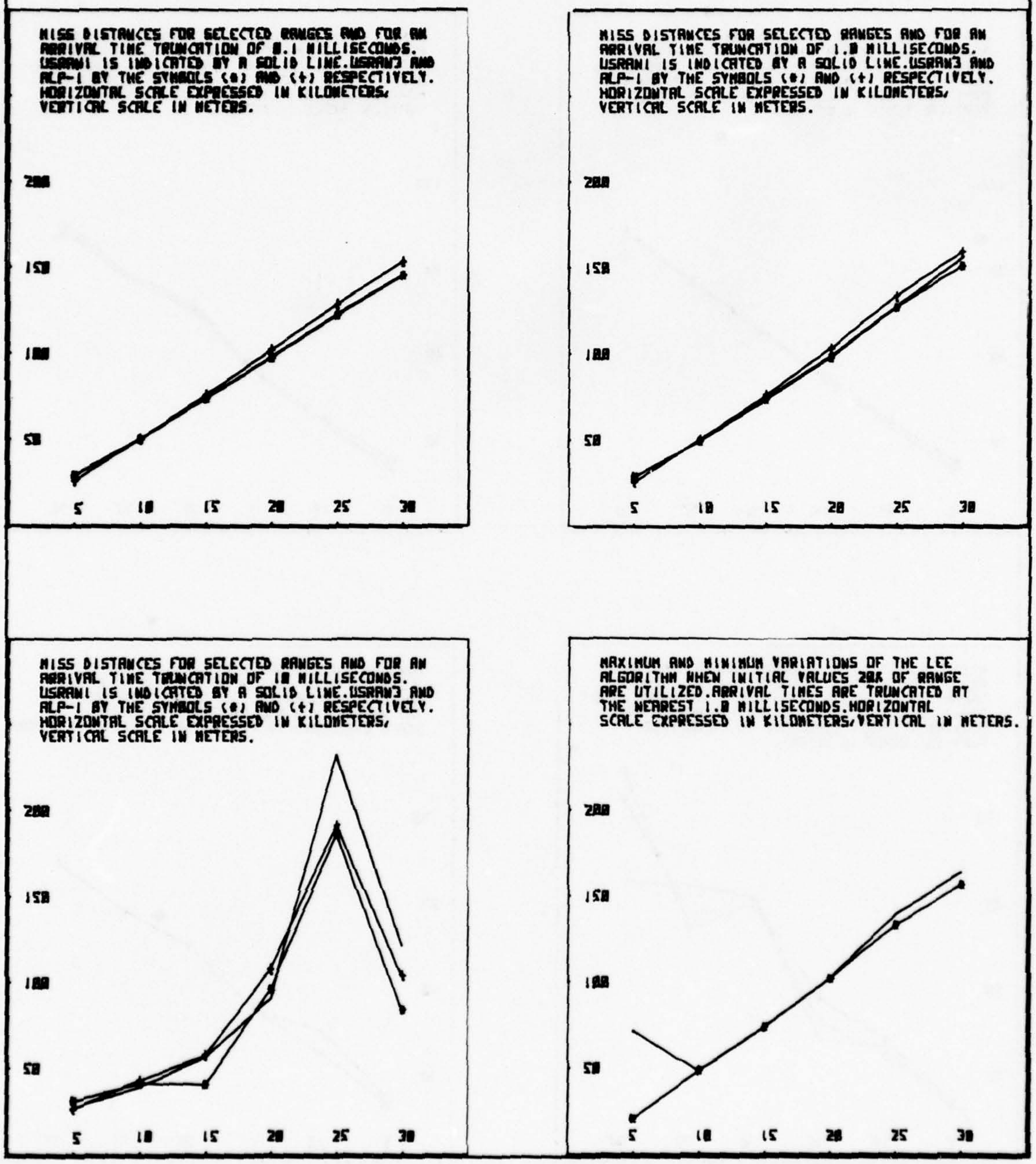
MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 15 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. IN ADDITION, AN ERROR OF ONE METER PER SECOND IS ASSUMED IN THE EAST WIND COMPONENT.

FIGURE 29



MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 30 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. IN ADDITION, AN ERROR OF ONE METER PER SECOND IS ASSUMED IN THE WEST WIND COMPONENT.

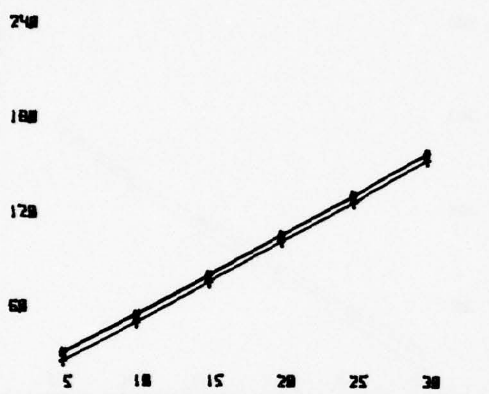
FIGURE 30



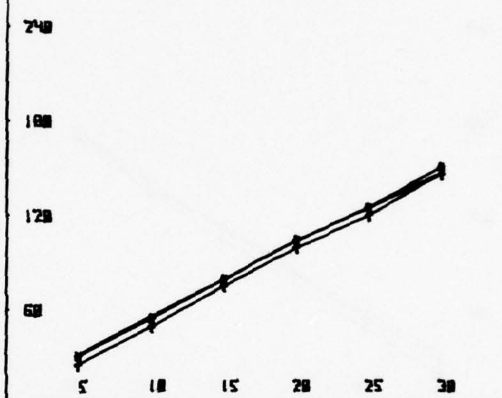
MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 30 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. IN ADDITION, AN ERROR OF ONE METER PER SECOND IS ASSUMED IN THE EAST WIND COMPONENT.

FIGURE 31

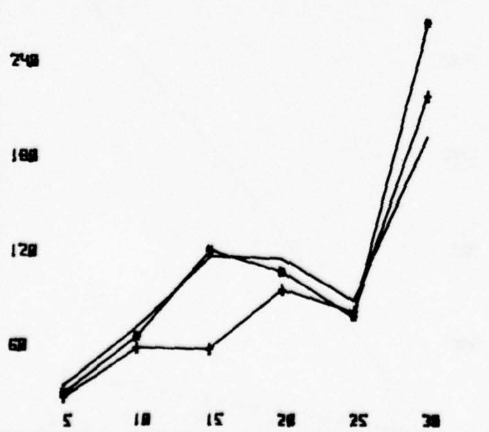
MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 0.1 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.



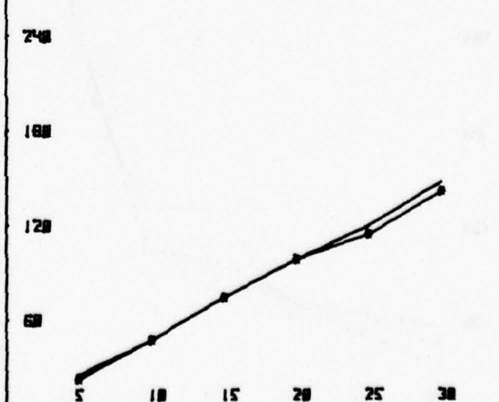
MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 1.0 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.



MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 10 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.

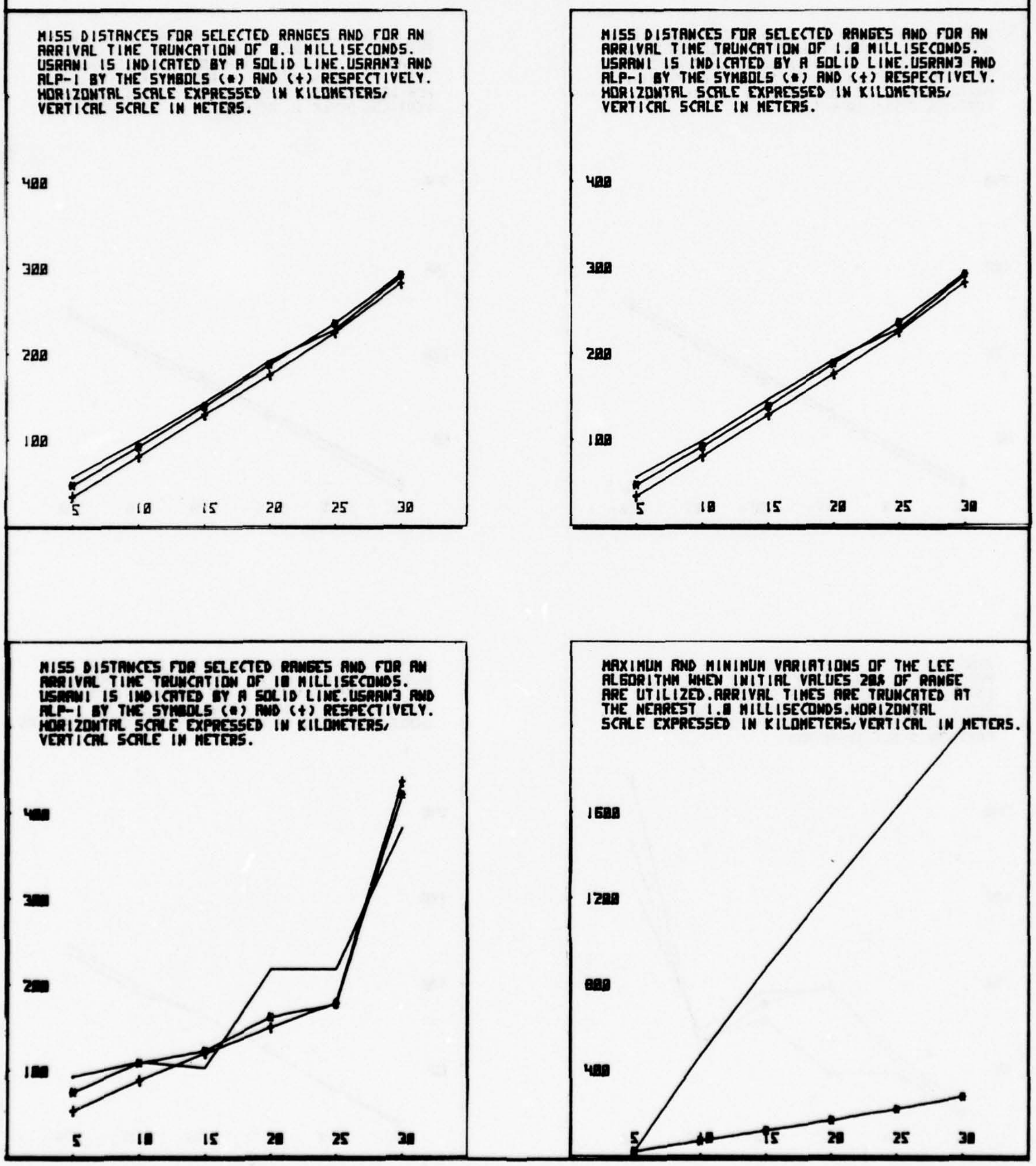


MAXIMUM AND MINIMUM VARIATIONS OF THE LEE ALGORITHM WHEN INITIAL VALUES 20% OF RANGE ARE UTILIZED. ARRIVAL TIMES ARE TRUNCATED AT THE NEAREST 1.0 MILLISECONDS. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL IN METERS.



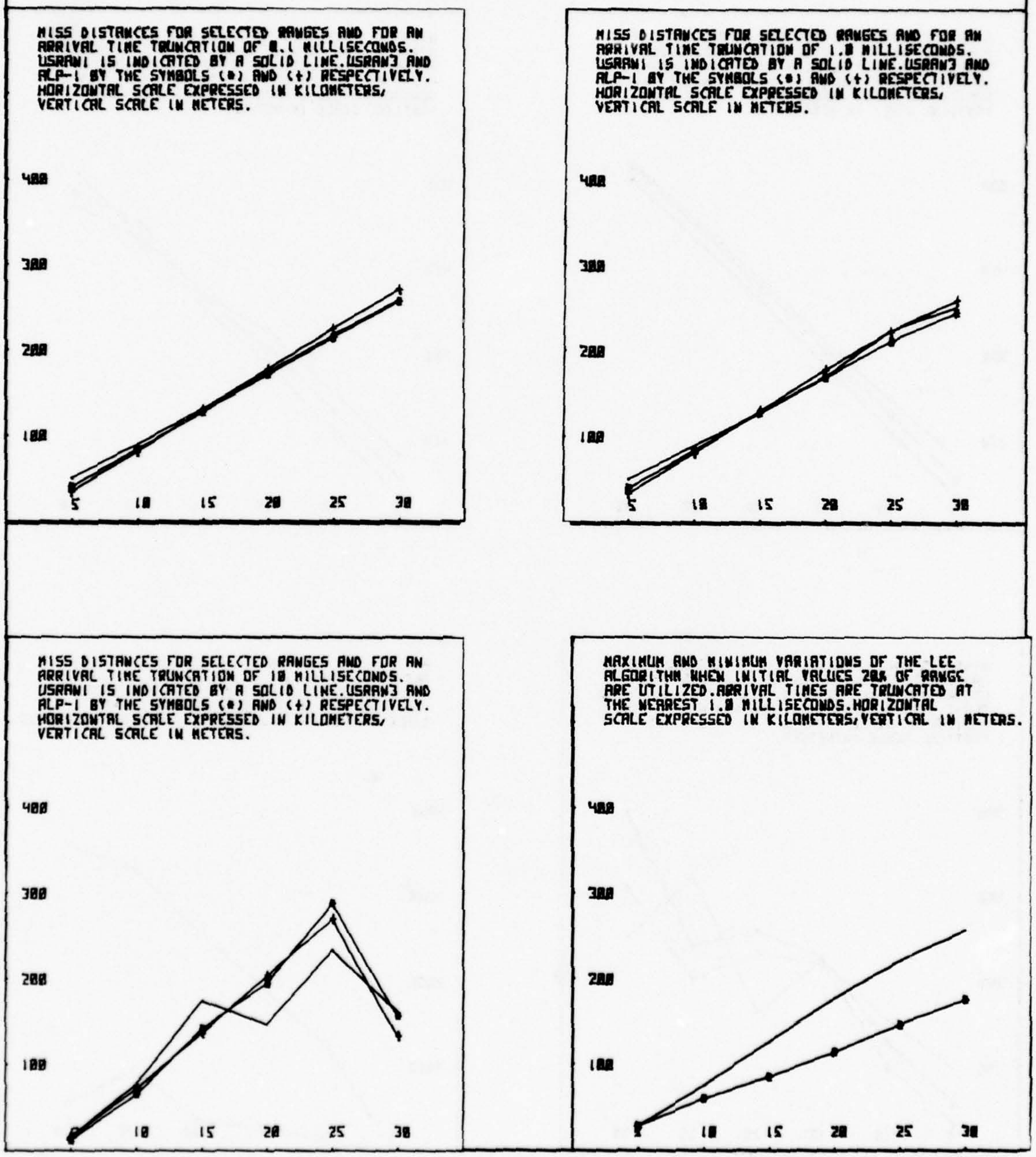
MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 45 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. IN ADDITION, AN ERROR OF ONE METER PER SECOND IS ASSUMED IN THE EAST WIND COMPONENT.

FIGURE 32



MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 45 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. IN ADDITION, AN ERROR OF ONE METER PER SECOND IS ASSUMED IN THE WEST WIND COMPONENT.

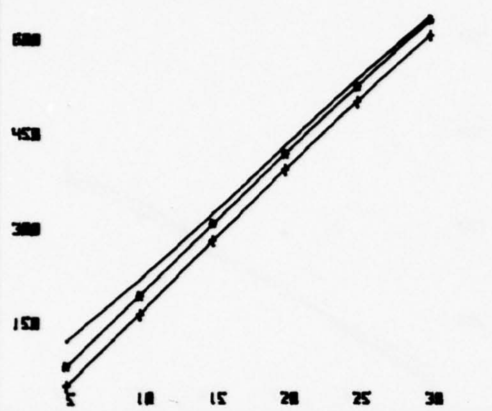
FIGURE 33



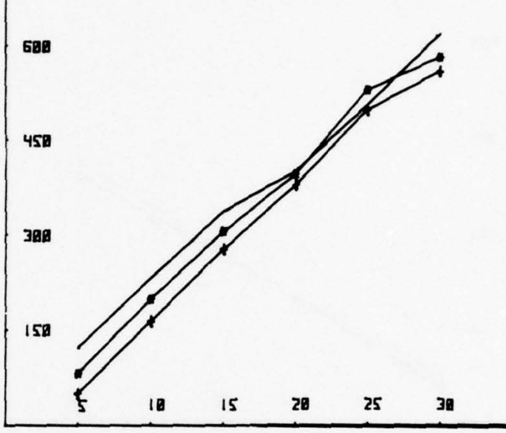
MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 60 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. IN ADDITION, AN ERROR OF ONE METER PER SECOND IS ASSUMED IN THE EAST WIND COMPONENT.

FIGURE 34

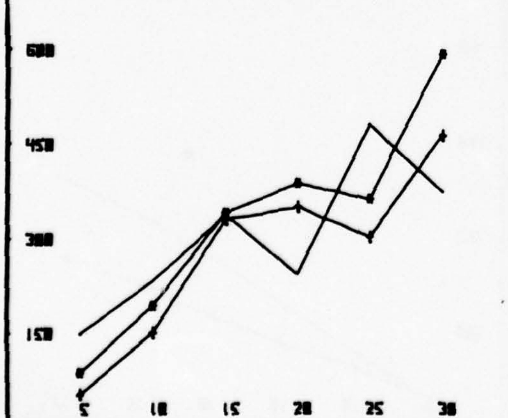
MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 0.1 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.



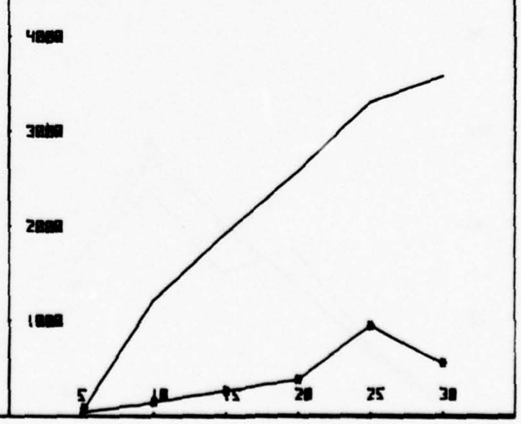
MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 1.0 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.



MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 10 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.



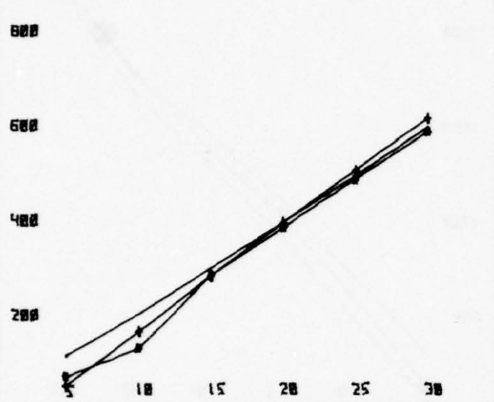
MAXIMUM AND MINIMUM VARIATIONS OF THE LEE ALGORITHM WHEN INITIAL VALUES 20% OF RANGE ARE UTILIZED. ARRIVAL TIMES ARE TRUNCATED AT THE NEAREST 1.0 MILLISECONDS. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL IN METERS.



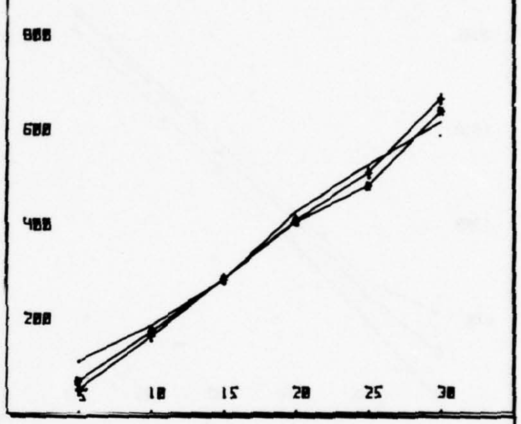
MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 60 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. IN ADDITION, AN ERROR OF ONE METER PER SECOND IS ASSUMED IN THE WEST WIND COMPONENT.

FIGURE 35

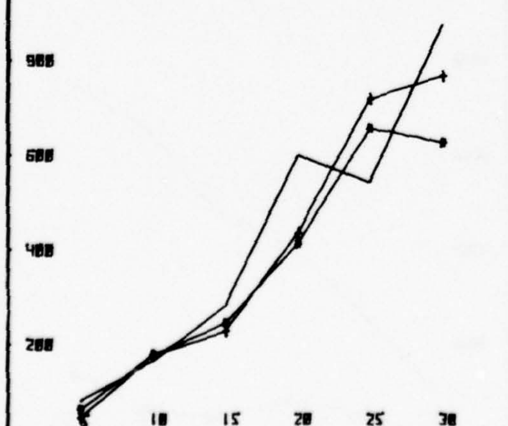
MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 0.1 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.



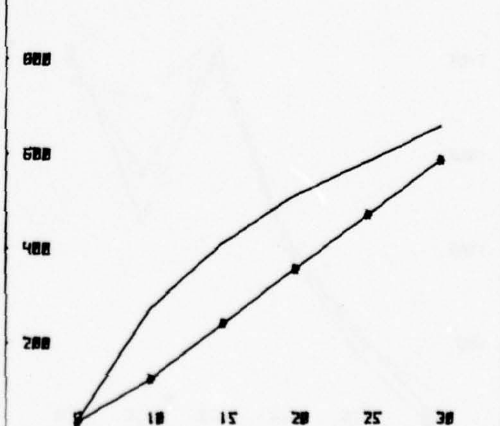
MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 1.0 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.



MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 10 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.

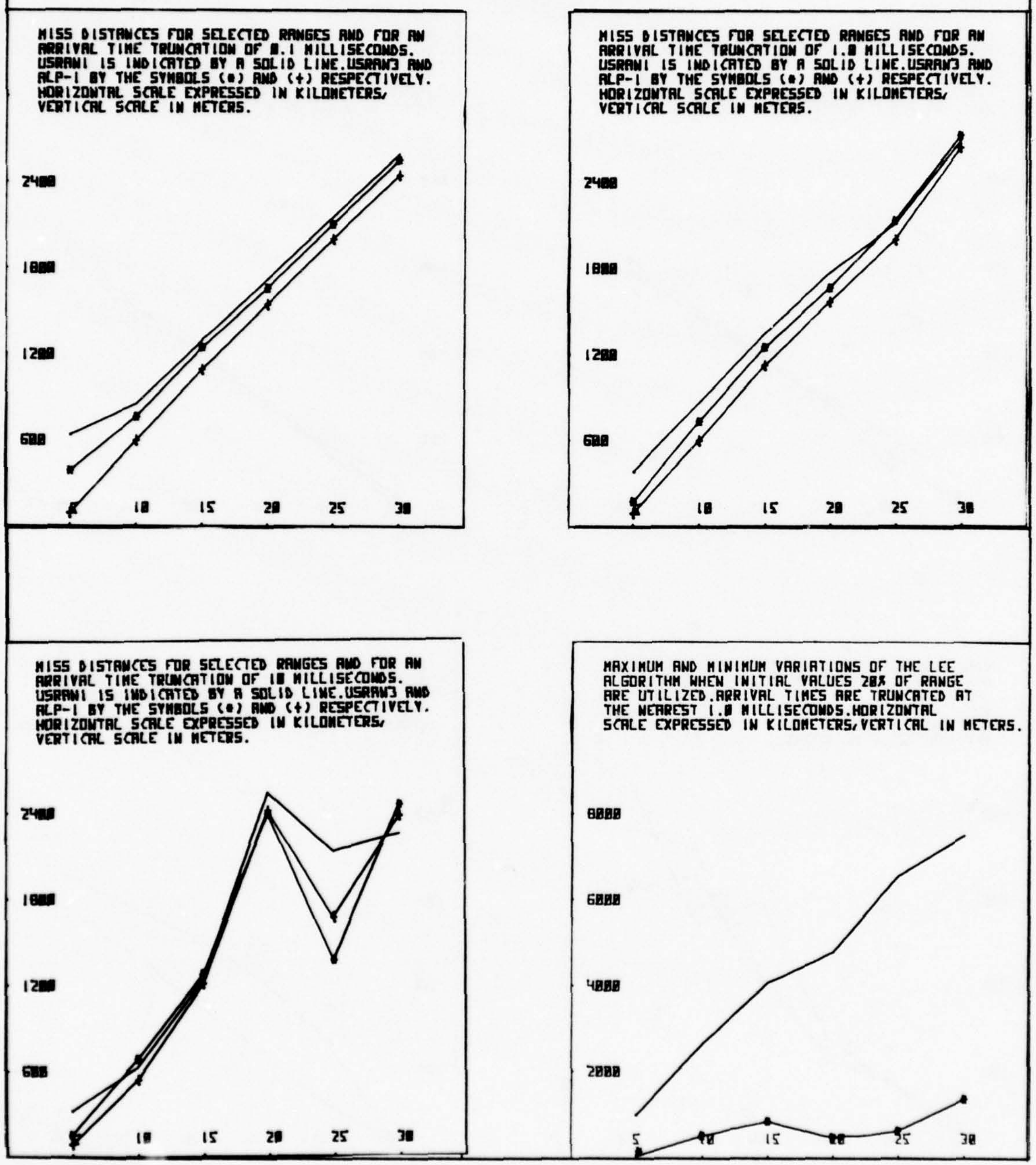


MAXIMUM AND MINIMUM VARIATIONS OF THE LEE ALGORITHM WHEN INITIAL VALUES 20% OF RANGE ARE UTILIZED. ARRIVAL TIMES ARE TRUNCATED AT THE NEAREST 1.0 MILLISECONDS. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL IN METERS.



MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 75 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. IN ADDITION, AN ERROR OF ONE METER PER SECOND IS ASSUMED IN THE EAST WIND COMPONENT.

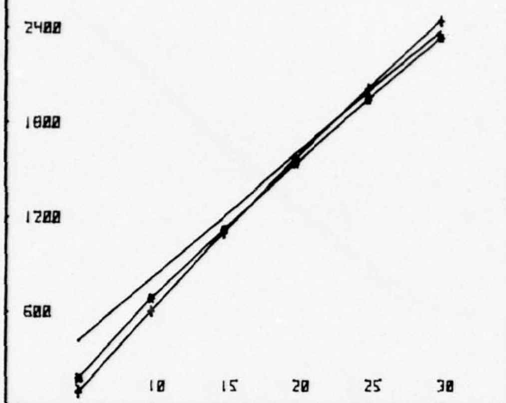
FIGURE 36



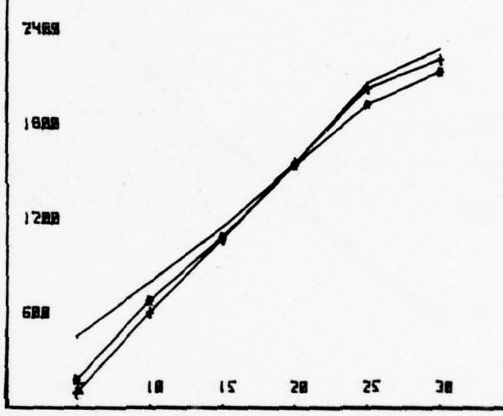
MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 75 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. IN ADDITION, AN ERROR OF ONE METER PER SECOND IS ASSUMED IN THE WEST WIND COMPONENT.

FIGURE 37

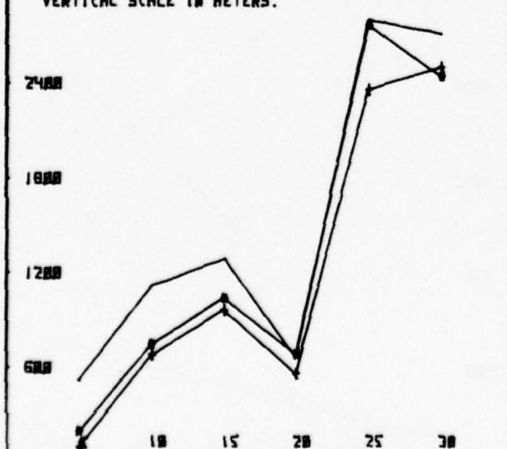
MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 0.1 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.



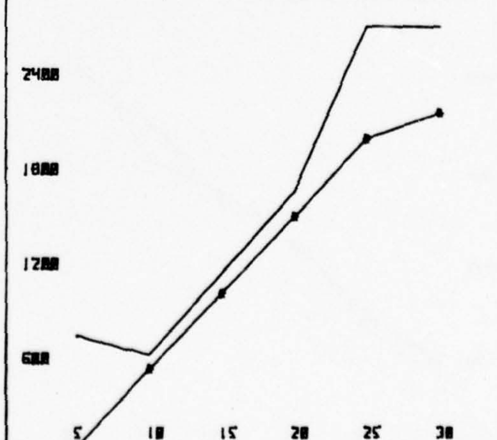
MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 1.0 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.



MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 10 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.



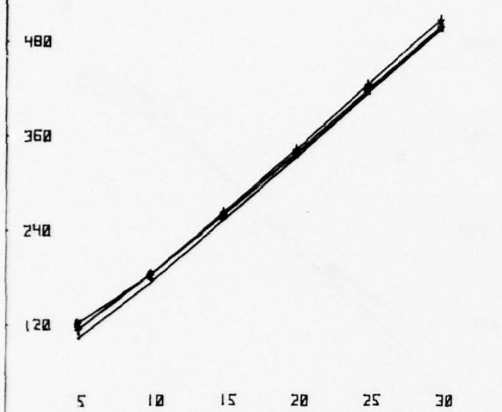
MAXIMUM AND MINIMUM VARIATIONS OF THE LEE ALGORITHM WHEN INITIAL VALUES 20% OF RANGE ARE UTILIZED. ARRIVAL TIMES ARE TRUNCATED AT THE NEAREST 1.0 MILLISECONDS. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL IN METERS.



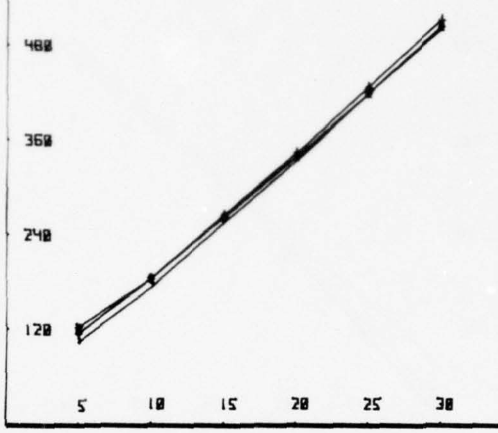
MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 0 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. IN ADDITION, A TEMPERATURE ERROR OF 5.0 DEGREES KELVIN IS ASSUMED TOGETHER WITH SOUTH AND WEST COMPONENT ERRORS OF 5.0 METERS/SECOND.

FIGURE 38

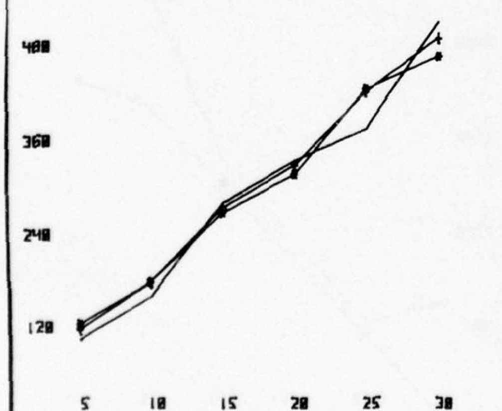
MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 0.1 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.



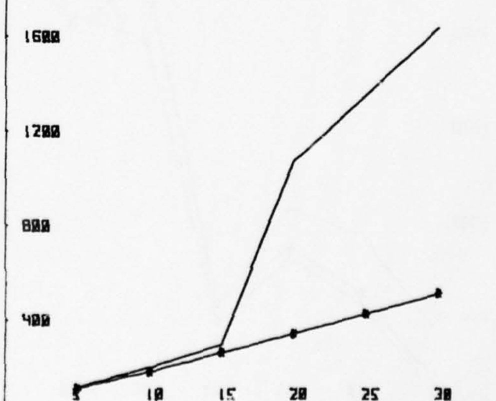
MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 1.0 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.



MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 10 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.

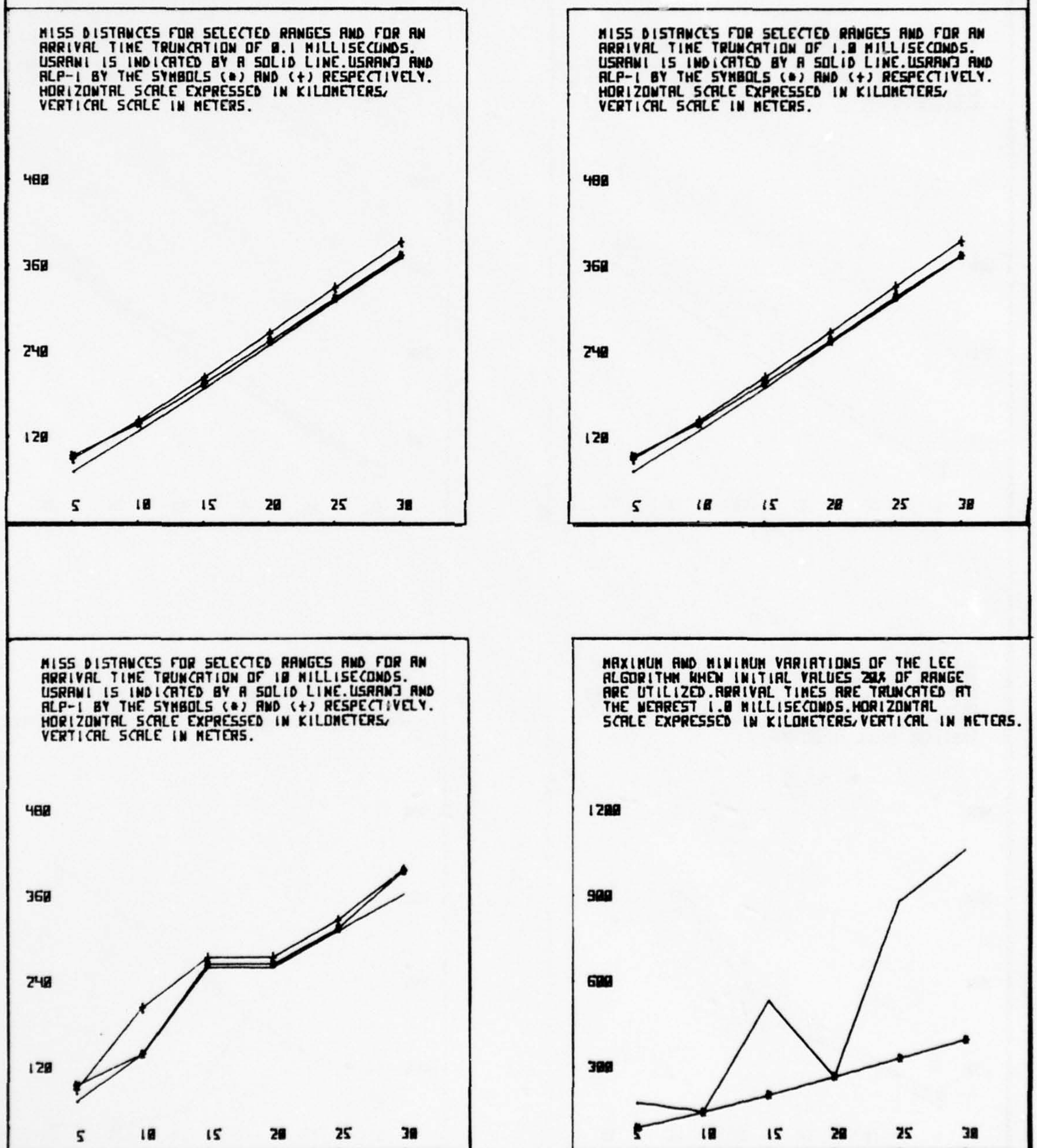


MAXIMUM AND MINIMUM VARIATIONS OF THE LEE ALGORITHM WHEN INITIAL VALUES 20% OF RANGE ARE UTILIZED. ARRIVAL TIMES ARE TRUNCATED AT THE NEAREST 1.0 MILLISECONDS. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL IN METERS.



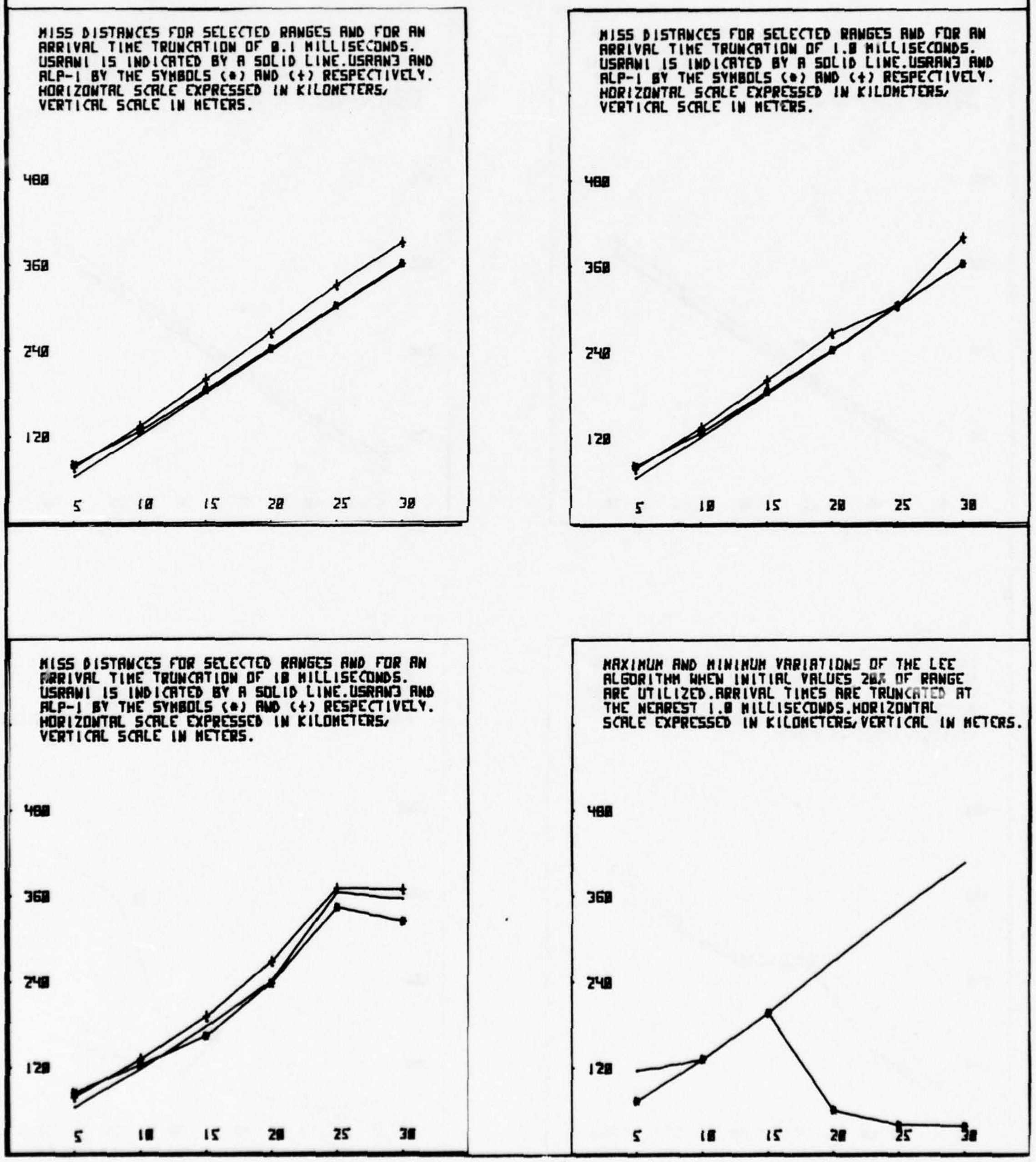
MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 15 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. IN ADDITION, A TEMPERATURE ERROR OF 5.Ø DEGREES KELVIN IS ASSUMED TOGETHER WITH SOUTH AND WEST COMPONENT ERRORS OF 5.Ø METERS/SECOND.

FIGURE 39



MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 30 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. IN ADDITION, A TEMPERATURE ERROR OF 5.0 DEGREES KELVIN IS ASSUMED TOGETHER WITH SOUTH AND WEST COMPONENT ERRORS OF 5.0 METERS/SECOND..

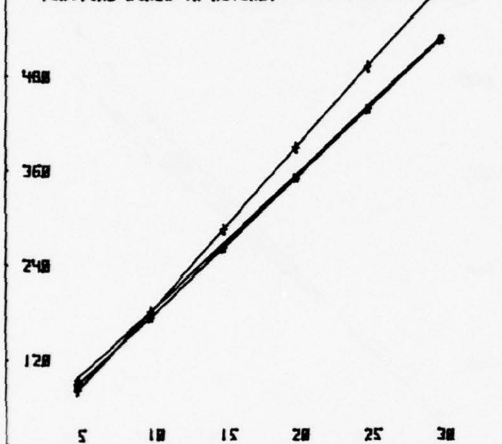
FIGURE 40



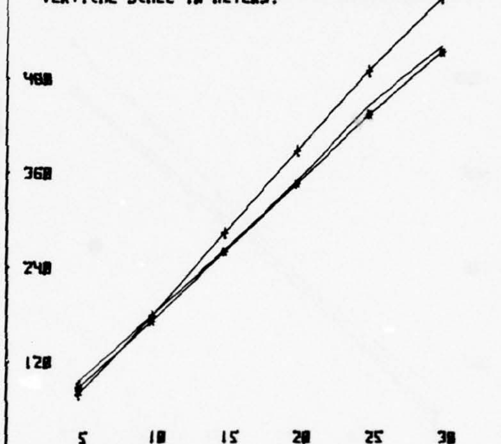
MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 45 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. IN ADDITION, A TEMPERATURE ERROR OF 5.0 DEGREES KELVIN IS ASSUMED TOGETHER WITH SOUTH AND WEST COMPONENT ERRORS OF 5.0 METERS/SECOND.

FIGURE 41

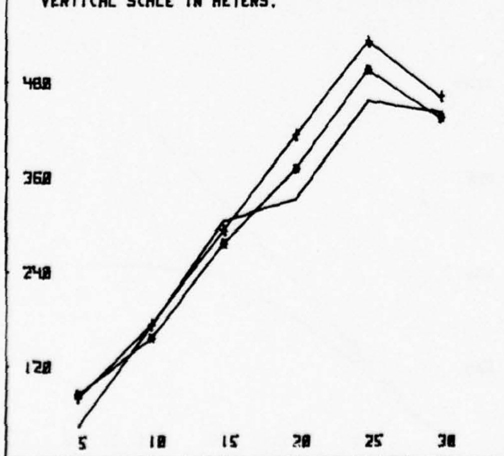
MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 0.1 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.



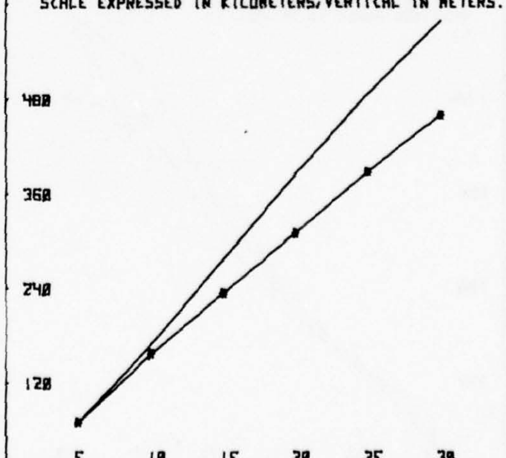
MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 1.0 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.



MISS DISTANCES FOR SELECTED RANGES AND FOR AN ARRIVAL TIME TRUNCATION OF 10 MILLISECONDS. USRAN1 IS INDICATED BY A SOLID LINE. USRAN3 AND ALP-1 BY THE SYMBOLS (*) AND (+) RESPECTIVELY. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL SCALE IN METERS.

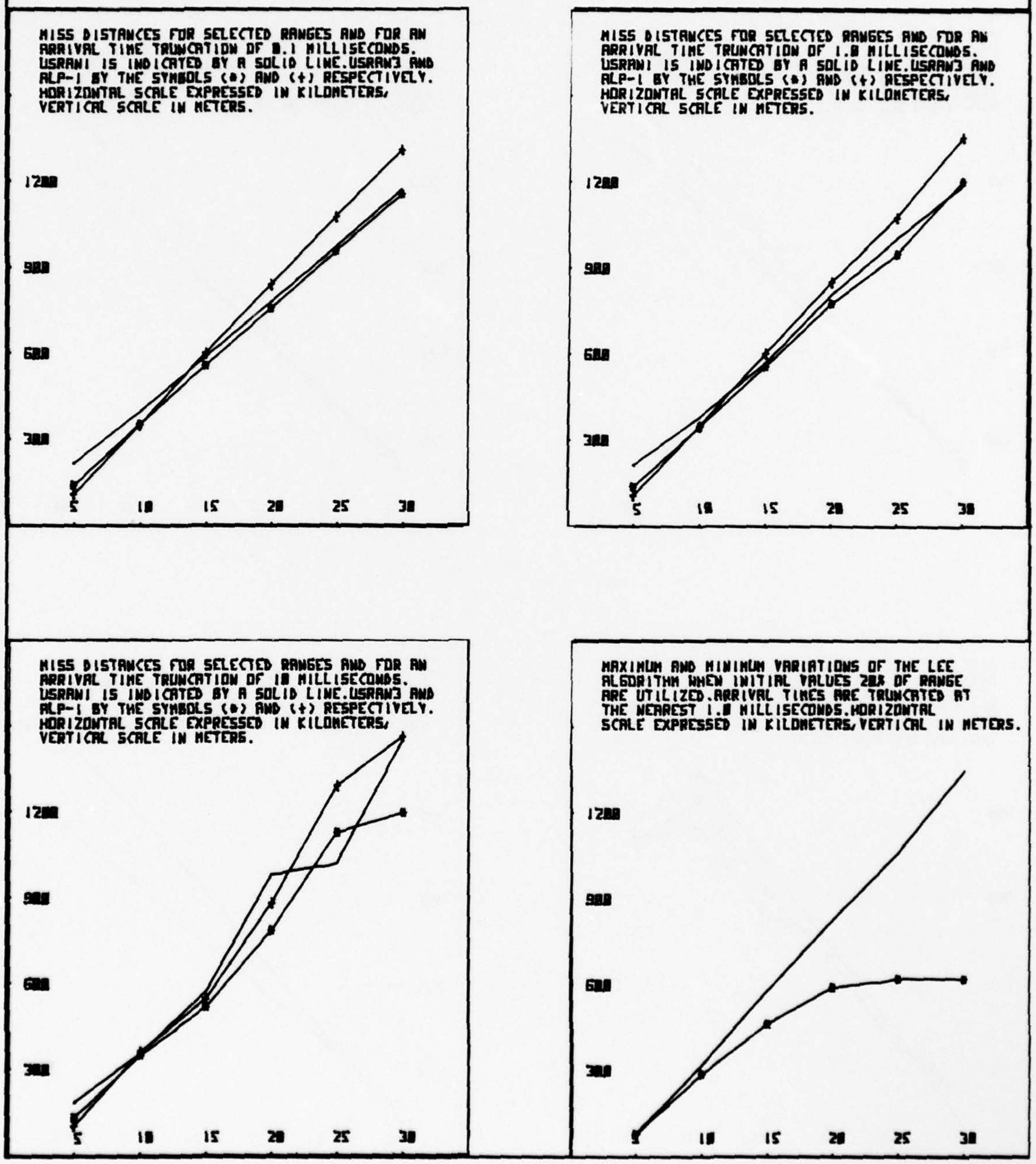


MAXIMUM AND MINIMUM VARIATIONS OF THE LEE ALGORITHM WHEN INITIAL VALUES 20% OF RANGE ARE UTILIZED. ARRIVAL TIMES ARE TRUNCATED AT THE NEAREST 1.0 MILLISECONDS. HORIZONTAL SCALE EXPRESSED IN KILOMETERS, VERTICAL IN METERS.



MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 6Ø DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. IN ADDITION, A TEMPERATURE ERROR OF 5.Ø DEGREES KELVIN IS ASSUMED TOGETHER WITH SOUTH AND WEST COMPONENT ERRORS OF 5.Ø METERS/SECOND.

FIGURE 42



MISS DISTANCE VERSUS RANGE (METERS) FOR SOURCE POINTS LOCATED AT A 75 DEGREE FLANKING ANGLE. SELECTED TRUNCATION POINTS ARE CONSIDERED AS INDICATED BELOW. IN ADDITION, A TEMPERATURE ERROR OF 5.0 DEGREES KELVIN IS ASSUMED TOGETHER WITH SOUTH AND WEST COMPONENT ERRORS OF 5.0 METERS/SECOND.

FIGURE 43

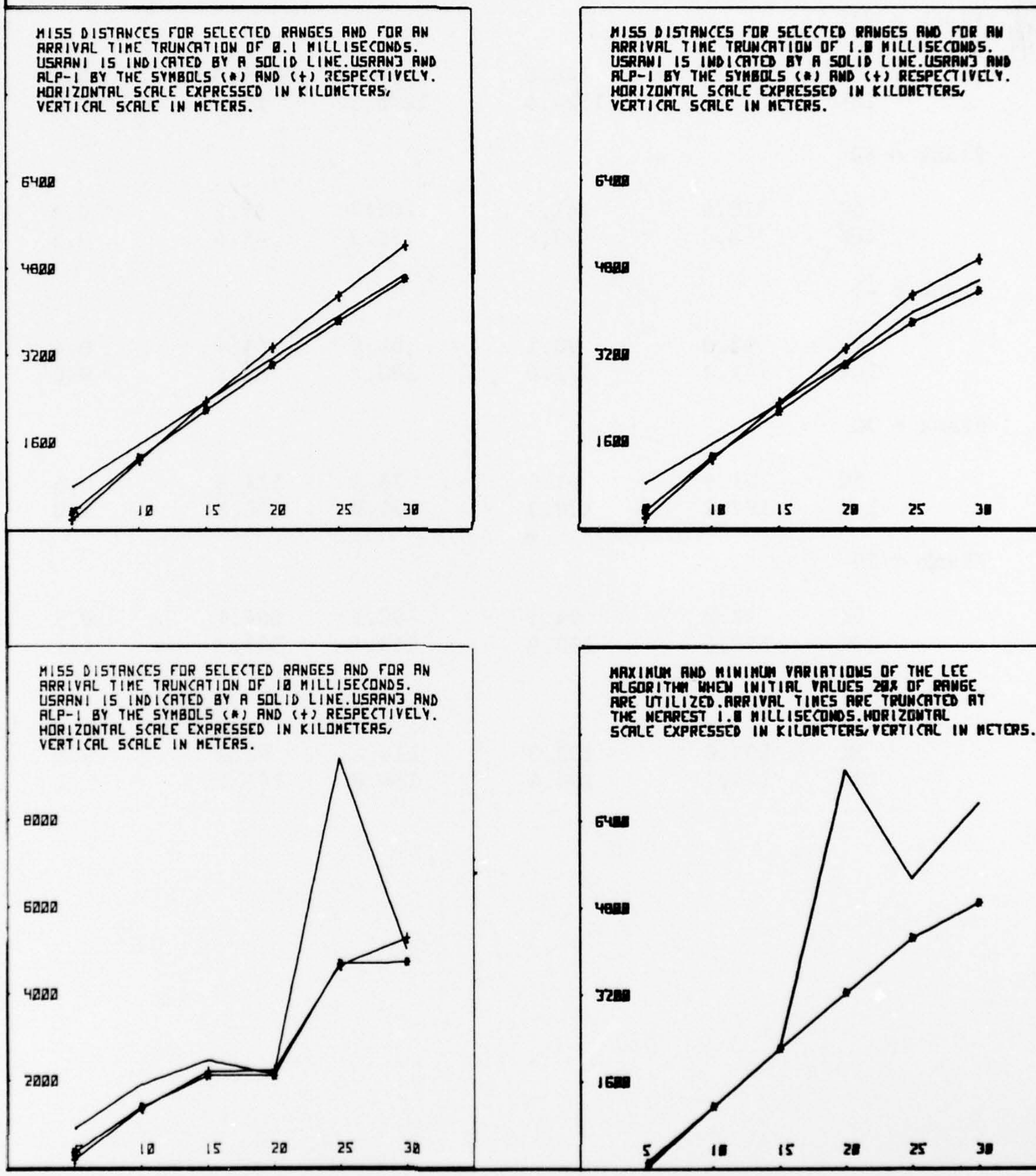


TABLE 1. MISS-DISTANCES (METERS) FOR SELECTED RANGES AND VARIOUS FLANKING ANGLES AS INDICATED. MAXIMUM TIMING ACCURACY IS EMPLOYED, AND METEOROLOGICAL ERRORS ARE ASSUMED OF 5.0 DEGREES KELVIN IN TEMPERATURE AND 5 METERS/SECOND IN SOUTH AND WEST WIND COMPONENTS.

Range	USRAN 1	USRAN 3	ALP-1	ALP-2T	ALP-2
Flank = 75					
5K	813.1	346.0	199.7	15.0	0.1
10K	1572.4	1324.6	1276.5	19.9	0.3
Flank = 60					
5K	218.6	141.9	109.7	35.2	0.3
10K	398.0	353.6	351.3	45.4	0.5
Flank = 45					
5K	98.0	90.1	81.9	64.4	0.4
10K	181.2	173.6	180.2	82.6	0.0
Flank = 30					
5K	61.6	81.6	78.2	111.8	0.5
10K	122.2	128.3	134.9	146.8	1.0
Flank = 15					
5K	72.8	94.5	90.5	204.1	0.5
10K	128.5	138.9	143.1	305.7	1.1
Flank = 0					
5K	103.8	122.3	114.7	98.2	0.5
10K	174.7	184.4	184.6	161.1	1.1

TABLE 2. MISS-DISTANCES (METERS) FOR SELECTED RANGES AND VARIOUS FLANKING ANGLES AS INDICATED. MILLISECOND TIMING ACCURACY IS EMPLOYED, AND METEOROLOGICAL ERRORS ARE ASSUMED OF 5.0 DEGREES KELVIN IN TEMPERATURE AND 5 METERS/SECOND IN SOUTH AND WEST WIND COMPONENTS.

Range	USRAN 1	USRAN 3	ALP-1	ALP-2T	ALP-2
Flank = 75					
5K	847.5	342.1	199.7	15.3	21.3
10K	1559.4	1321.2	1275.8	24.1	*
Flank = 60					
5K	216.7	140.6	109.4	34.8	7.7
10K	381.4	347.1	350.4	49.4	250.4
Flank = 45					
5K	98.4	90.6	81.8	65.0	3.4
10K	181.8	174.1	180.7	85.4	19.0
Flank = 30					
5K	65.5	81.7	78.3	111.3	1.4
10K	121.9	127.9	134.9	137.3	36.1
Flank = 15					
5K	73.3	44.2	90.6	200.9	2.2
10K	128.8	139.2	143.2	296.8	5.7
Flank = 0					
5K	104.5	122.7	115.0	98.6	7.2
10K	173.2	184.1	184.1	196.6	115.9

*Unstable

TABLE 3. MISS-DISTANCES (METERS) FOR SELECTED RANGES AND VARIOUS FLANKING ANGLES AS INDICATED. TEN-MILLISECOND TIMING ACCURACY IS EMPLOYED, AND METEOROLOGICAL ERRORS ARE ASSUMED OF 5.0 DEGREES KELVIN IN TEMPERATURE AND 5 METERS/SECOND IN SOUTH AND WEST WIND COMPONENTS.

Range	USRAN 1	USRAN 3	ALP-1	ALP-2T	ALP-2
Flank = 75					
5K	927.6	367.2	206.8	18.5	78.6
10K	1914.8	1398.1	1362.9	18.8	*
Flank = 60					
5K	188.3	135.2	106.1	36.7	85.8
10K	360.8	352.0	363.4	108.5	*
Flank = 45					
5K	95.6	85.5	81.4	68.3	22.3
10K	171.0	155.7	172.9	76.4	*
Flank = 30					
5K	66.2	85.8	79.4	99.7	20.8
10K	118.5	124.4	132.1	127.4	*
Flank = 15					
5K	73.0	95.5	89.8	187.9	10.3
10K	137.9	138.3	143.9	148.9	*
Flank = 0					
5K	106.3	125.6	118.5	110.7	52.5
10K	161.7	180.3	180.1	901.6	*

*Unstable

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